Foundation Investigation and Design Report

Culvert Replacements, Structure Nos. 34-326/C, 34-331/C and 34-458/C, Highway 3 and 140, City of Port Colbourne and City of Welland, Ontario
Ministry of Transportation, Ontario, G.W.P. 2374-15-00

Submitted to:

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GEOCRES No.: **30L14-62**

Culvert No.	LATITUDE	LONGITUDE
34-326/C	42.980947	-79.204872
34-331/C	42.893553	-79.186572
34-458/C	42.961392	-79.207213

Distribution List

1 PDF & 1 Copy - Ministry of Transportation, Ontario (Central Region)

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PART A

FOUNDATION INVESTIGATION REPORT

CULVERT REPLACEMENTS, STRUCTURE NOS. 34-326/C, 34-331/C AND 34-458 /C, HIGHWAY 3 AND HIGHWAY 140, NIAGARA REGION

MTO, G.W.P. 2374-15-00

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by AIA Engineers LLC (AIA) on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation engineering services for the rehabilitation / replacement of three culverts as detailed below:

- Culvert Site No. 34-326/C, Highway 140, at Lyons Creek, City of Welland, Ontario
- Culvert Site No. 34-331/C, Highway 3, West of White Road, City of Port Colborne, Ontario
- Culvert Site No. 34-458/C, Highway 140, North of Highway 58A, City of Port Colborne, Ontario

The purpose of this investigation is to explore the subsurface soil, bedrock and groundwater conditions at the culvert sites by borehole drilling / bedrock coring and geotechnical laboratory testing and analytical chemistry laboratory testing on selected soil and bedrock samples.

The Terms of Reference (TOR) and Scope of Work for the foundation investigation are outlined in MTO's Request for Quotation, dated December 2017, which forms part of the Consultant's Assignment Number 2017-E-0068 for this project. The work has been carried out in accordance with Golder's Supplementary Specialty Plan for foundation engineering services for this project, dated September 2018.

2.0 SITE DESCRIPTION

Existing Culvert Site Nos. 34-326/C and 34-458/C are located along Highway 140 in the City of Welland and the City of Port Colborne, Ontario, respectively and existing Culvert Site No. 34-331/C is located along Highway 3 in Port Colborne, Ontario.

Highway 140 consists of one lane in each direction and is oriented in a north-south direction. Existing Culvert Site Nos. 34-326/C and 34-458/C are generally oriented in an east-west direction. Culvert 34-326/C conveys water from Lyons Creek from a southwest to northeast direction. The existing culvert consists of a 3.3 m wide corrugated steel arch culvert that is approximately 38 m long. At this location, the culvert site is surrounded by farm fields with the exception of the southwest quadrant where a solar farm is located. Culvert Site No. 34-458/C conveys surface water from the west to the east and consists of a 3.75 m wide corrugated steel arch culvert that is approximately 32 m long. At this location, the culvert site has a residential property located to the west of the culvert site and industrial properties are located on the east side of the site. The road surface of Highway 140 at Culvert Site No. 34-326/C is between about 2.9 m and 4.8 m above the toe of the embankment slope and at Culvert Site No. 34-458/C the road surface of Highway 140 is about 1 m above the toe of the embankment slope. Culvert Site No. 34-326/C is shown in Photographs 1 and 2. Culvert Site No. 34-458/C is shown in Photograph 4 and the channel sideslopes are shown in Photograph 5.

Highway 3 is oriented in an east-west direction, and existing Culvert Site No. 34-331/C is generally oriented in a north-south direction and conveys water from north to south. Highway 3 consists of one lane in each direction and residential properties are located surrounding the culvert site. The existing culvert is approximately 20 m long and comprised of three sections; a central (original) 3.5 m diameter, open-footing, reinforced concrete, arch culvert with two end-sections (extensions to the original) that are both 3.5 m wide, open-footing, reinforced concrete, rigid frame box culverts. No evidence of seepage or sloughing was noted at the existing embankment slopes at Culvert Site No. 34-331/C. Culvert 34-331/C is shown on Photograph 3.

Culvert Site Nos. 34-326/C, 34-331/C and 34-458/C were inspected and the highway embankments in the vicinity of the existing culverts appear to be performing appropriately, from a geotechnical perspective. No settlement or cracking of the culvert is apparent from the field reconnaissance completed as part of the investigation. The nearby embankments are vegetated with grasses and low shrubs, there is no apparent seepage on the face or at the toes of the embankment and there are no signs of sloughing or erosion.

3.0 INVESTIGATION PROCEDURES

3.1 Previous Investigation

From December 4 to 6, 1969, a foundation investigation for the Lyons Creek Culvert (Structure No. 34-326/C) was carried out by the Department of Highways Ontario, during which time a total of six boreholes were drilled. The results of the Department of Highways Ontario investigation are contained in report titled,

- “Foundation Investigation Report for Proposed Multi-Plate Arch Culvert at the Crossing of Hwy. #140 and Lyons Creek, Twp. Of Crowland, County of Welland, District No. 4 (Hamilton), W.J. 69-F-64, W.P. 60-68-04”, dated December 22, 1969 (GEOCRES 30L14-030).

Of the six boreholes advanced Borehole 1 is located in close proximity to inlet of the culvert. While the above noted Department of Highways Ontario report does not reference a coordinate system for the borehole locations, Boreholes 1 from the Borehole Locations and Soil Strata drawing provided in the 1969 report was plotted on Drawing 1 based on common site features and the borehole coordinates were interpreted from the coordinate system superimposed on the plan. The estimated borehole location in MTM NAD 83 Zone 10 Coordinates, geographic coordinates (latitude / longitude), the ground surface elevation in Geodetic Datum, and the drilled depth as presented on or derived from the 1969 borehole record is summarized below.

Borehole No.	Location (MTM NAD 83, Zone 10)[1]		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing (Latitude, °)	Easting (Longitude, °)		
1	4,760,174.8 (42.981004)	328,855.7 (-79.205051)	174.8	20.7

1. Coordinates are approximate and have been estimated based on the “Borehole Locations and Soil Strata” drawing provided in GEOCRES 30L14-030.

3.2 Current Investigation

Field work was carried out between January 8 and March 21, 2019, during which time a total of ten boreholes, designated as Boreholes 326-1 to 326-4, 331-1 and 331-2, and 458-1 to 458-4 and one test pit, designated as 331-3 were advanced at the three culvert site locations as shown on Drawings 1, 2, and 3. Test Pit 331-3, was excavated at Culvert Structure No. 34-331/C to assess the topsoil thickness adjacent to the existing culvert.

Field drilling was carried out using a track-mounted CME 75 drilling rig and a truck-mounted CME 55 drilling rig supplied and operated by Geo-Environmental Drilling Inc., of Halton Hills, Ontario, and a track-mounted D50 drilling rig and a Portable Tripod drilling rig with a manual hammer drive system supplied and operated by Walker Drilling Ltd., of Utopia, Ontario. With the exception of Borehole 326-4, the boreholes were advanced through the overburden using 70 mm and 114 mm inner diameter hollow-stem augers. Borehole 326-4 was advanced using 125 mm outer diameter casing with wash boring techniques. Test Pit 331-3 was advanced manually by hand excavation with a shovel. Soil samples were obtained at 0.6 m, 0.75 m and 1.5 m intervals of depth, using a 50 mm outer diameter split-spoon sampler driven by an automatic hammer or a manual hammer in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586-11)[1]. Field vane shear tests were carried out in the cohesive soils for assessment of undrained shear strength (ASTM D2573[2]) using MTO standard N-size vanes. Samples of the bedrock were obtained using an 'HQ' size core barrel and coring techniques in the boreholes advanced for Culvert Structure No. 34-331/C. The boreholes were advanced to depths between 3.7 m and 17.4 m below existing ground surface, including coring of bedrock for core lengths of between 3.1 m and 3.2 m in Boreholes 331-1 and 331-2. The test pit was advanced to a depth of 0.2 m below existing ground surface.

Groundwater conditions and water levels in the open boreholes were observed during and immediately following drilling operations. A standpipe piezometer was installed in Boreholes 326-1 and 458-4 to allow monitoring of the water level at the borehole locations. The standpipe piezometers consist of a 50 mm diameter PVC pipe with a slotted screen. The annulus surrounding the piezometer screen was backfilled with a filter sand pack. The section of borehole below the standpipe piezometer was backfilled with bentonite to the underside of the sand pack level, and the remainder of the borehole above the sand pack was backfilled with bentonite to near the ground surface and topped with concrete or sand and gravel to match the adjacent ground surface material. All boreholes were backfilled with bentonite upon completion in accordance with Ontario Regulation 903: Wells (as amended) and Boreholes 326-2, 326-3, 331-1, and 331-2 were topped with cold patch asphalt or sand and gravel to match the adjacent ground surface material.

Field work was observed by members of Golder's engineering and technical staff, who located the boreholes, arranged for the clearance of underground services including both public and, where applicable, private locates, observed the drilling, sampling and in-situ testing operations, logged the boreholes, and examined the soil samples. The samples were identified in the field, placed in appropriate containers, labelled and transported to Golder's Mississauga geotechnical laboratory where the samples underwent further visual examination and geotechnical laboratory testing. All the geotechnical laboratory tests were carried out in accordance with MTO and/or ASTM Standards, as appropriate. Classification testing (water content, Atterberg limits, grain size distribution and organic content) was carried out on selected soil samples. Selected rock core samples were submitted to Golder's Mississauga geotechnical laboratory for unconfined compression (UC) testing.

Six selected soil samples were submitted, under chain-of-custody procedures, to Maxxam Analytics of Mississauga, Ontario (a Standards Council of Canada (SCC) accredited laboratory) for a suite of characteristics that indicate corrosivity potential including pH, resistivity, conductivity, chloride content and sulphate content.

The as-drilled borehole locations and the ground surface elevations were obtained using a GPS (Trimble Geo-7X), having an accuracy of approximately 0.1 m in the vertical and 0.1 m in the horizontal directions. The locations given

[1] ASTM D1586-11 – Standard Test Method for Standard Penetration Tests and Split Barrel Sampling of the soil, ASTM International, West Conshohocken, PA, 2015

[2] ASTM D2573-15 Standard Test Method for Field Vane Shear Test in Saturated Fine-Grained Soils, ASTM International, West Conshohocken, PA, 2015

on the Record of Borehole / Testpit / Drillhole sheets and shown on Drawings 1 to 3 are positioned relative to MTM NAD 83 (Zone 10) CSRS CBNV6-2010.0 northing and easting coordinates and the ground surface elevations are referenced to Geodetic datum. The borehole locations, geographic coordinates, ground surface elevations and drilled depths are summarized below.

Borehole / Test Pit No.	Location (MTM NAD 83 Zone 10)		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing (m) (Latitude)	Easting (m) (Longitude)		
Culvert Site No. 34-326/C				
326-1	4,760,176.1 (42.981016)	328,858.8 (-79.205013)	175.1	6.7
326-2	4,760,168.5 (42.980947)	328,870.4 (-79.204872)	177.9	17.4
326-3	4,760,190.9 (42.981149)	328,875.1 (-79.204812)	178.0	15.9
326-4	4,760,180.1 (42.981051)	328,885.9 (-79.204681)	175.1	3.7
Culvert Site No. 34-331/C				
331-1	4,750,461.7 (42.893513)	330,386.1 (-79.186731)	179.3	7.5 (including 3.18 m of bedrock core)
331-2	4,750,466.1 (42.893553)	330,399.0 (-79.186572)	179.3	7.5 (including 3.08 m of bedrock core)
331-3[1]	4,750,469.8 (42.893577)	330,399.7 (-79.186564)	178.9	0.2
Culvert Site No. 34-458/C				
458-1	4,758,013.7 (42.961555)	328,680.5 (-79.207292)	178.7	15.9
458-2	4,757,995.7 (42.961392)	328,686.9 (-79.207213)	179.6	17.4
458-3	4,758,012.8 (42.961546)	328,704.4 (-79.206999)	179.5	17.4
458-4	4,758,016.8 (42.961582)	328,714.7 (-79.206873)	179.3	14.9

1. Test Pit

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

The project area is located within the Haldimand Clay Plain Physiographic Region and partially within either the Clay Plains or Limestone Plains Physiographic Landforms, as delineated in *The Physiography of Southern Ontario*[3]. Based on mapping by the Ontario Geological Survey (2011)[4], the bedrock in the vicinity of the structure sites consists of limestone, dolostone and shale of the Salina and Onondaga Formations. The Physiographic Landform and Bedrock Formation at each structure site is summarized below:

Culvert / Bridge Site Number	Physiographic Landform	Bedrock Formation
Culvert No. 34-326/C Highway 140, Welland	Clay Plains	Salina Formation (57c) – shale and argillaceous dolostone
Culvert No. 34-458/C Highway 140, Welland		
Culvert No. 34-331/C Highway 3, Port Colborne	Limestone Plains	Onondaga Formation (59d) – limestone, argillaceous limestone, and minor shale

The Haldimand Clay Plain extends from approximately the Niagara Escarpment south to the shores of Lake Erie and consists of stratified clay and till with areas of sand and lacustrine silt and clay deposits. Generally, bedrock within the Haldimand Clay Plain is less than 15 m below ground surface at the north end near the Niagara Escarpment; south of this the bedrock surface is at depths of up to about 45 m below ground surface, and at the very south near the Lake Erie shore, the bedrock surface varies from about 3 m to 15 m below ground surface.

4.2 Subsurface Conditions

Subsurface soil, bedrock and groundwater conditions as encountered in the boreholes, details of the piezometer installations and water level readings, and the results of the geotechnical laboratory tests carried out on selected soil and bedrock core samples are presented on the Record of Borehole, Drillhole and Test Pit sheets provided in Appendix A for Culvert Site Nos. 34-326/C and 34-458/C, and Appendix B for Culvert Site No. 34-331/C. The subsurface conditions as encountered in the relevant borehole advanced during the previous investigation discussed in Section 3.1, is included in Appendix A, for Culvert 34-326/C. Photographs of the recovered bedrock core samples are presented on Figure B-7, in Appendix B. The results of in-situ field tests (i.e., SPT "N"-values and field vane undrained shear strengths) as presented on the Record of Borehole sheets and in sub-sections of Section 4.2 are uncorrected. Lists on abbreviations and symbols and lithological, geotechnical rock description terminology, field estimation of rock hardness and rock weathering classification are also included following the text of this report to assist in the interpretation of the borehole and drillhole records. The results of the geotechnical laboratory testing on the soil and bedrock samples are presented in Appendix A for Culvert Site Nos. 34-326/C and

[3] Chapman, L.J. and Putnam, D.F. 2007. *Physiography of southern Ontario*; Ontario Geological Survey, Miscellaneous Release--Data 228.

[4] Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release---Data 126-Revision 1.

34-458/C, and Appendix B for Culvert Site No. 34-331/C . The analytical laboratory test report is included in Appendix C and the test results are summarized in Section 4.3.

Stratigraphic boundaries shown on the Record of Borehole sheets and on the stratigraphic profile on Drawings 1 to 3 are inferred from non-continuous sampling, observations of drilling progress and the results of the Standard Penetration Tests. These boundaries, therefore, represent transitions between soil types rather than exact planes of geological change. Furthermore, subsurface conditions will vary between and beyond the borehole locations; however, the factual data presented in the borehole and drillhole records governs any interpretation of the site conditions. It should be noted that the interpreted stratigraphy shown on Drawings 1 to 3 is a simplification of the subsurface conditions at each of the culvert replacement sites.

4.2.1 Culvert Site Nos. 34-326/C and 34-458/C

In general, the subsurface conditions at these culvert sites consists of a layer of asphalt or topsoil underlain by fill materials consisting of clayey silt to gravelly silty clay to sand and gravel to gravel. The fill is underlain by a deep deposit of clayey silt to silty clay. A more detailed description of the subsurface conditions encountered in the boreholes from the previous and current investigations are provided in the following sections.

4.2.1.1 Asphalt

An approximately 400 mm thick layer of asphalt pavement was encountered at ground surface in Boreholes 326-2 and 326-3.

4.2.1.2 Topsoil

An approximately 50 mm to 100 mm thick layer of topsoil was encountered at ground surface in Boreholes 326-1, 326-4, and 458-1 and 458-4.

4.2.1.3 Fill

At Culvert Site No. 34-326/C a 1.7 m to 6.9 m thick layer of fill comprised of: sand and gravel, silty clay to clayey silt, and gravel and cobbles was encountered in Boreholes 326-1 to 326-4 underlying the topsoil or asphalt surface layer and in Borehole 1 (from the previous investigation) at the ground surface. Borehole 326-4 was advanced with portable drilling equipment and encountered casing refusal on cobbles at a depth of 3.7 m below ground surface; this borehole was terminated in the fill. An example of a large gravel-sized particle recovered from the cuttings of Borehole 326-4 is shown in Photograph 1 (below).

Photograph 1: Large gravel-sized particle from cuttings of Borehole 326-4

At Culvert Site No. 34-458/C a 0.7 m to 1.5 m thick layer of fill comprised of: silty gravelly sand to sand and gravel was encountered at ground surface in Boreholes 458-2, 458-3 The depth and elevation of the top and bottom of the fill material and the corresponding thickness and soil type are summarized below.

Culvert Site No.	Borehole No.	Top of Layer (below topsoil/pavement surface)		Bottom of Layer		Thickness (m)	Fill Type
		Depth (m)	Elevation (m)	Depth (m)	Elevation (m)		
34-326/C	326-1	0.1	175.0	4.1	171.0	4.0	Sand and Gravel
	326-2	0.4	177.5	0.8	177.1	0.4	Sand and Gravel
		0.8	177.1	1.5	176.4	0.7	Gravelly Silty Clay
		1.5	176.4	3.7	174.2	2.2	Silty Clay
		3.7	174.2	7.2	170.7	3.5	Sandy Gravel
	326-3	0.4	177.6	0.7	177.3	0.3	Sand and Gravel
		0.7	177.3	3.7	174.3	3.0	Silty Clay
		3.7	174.3	7.3	170.7	3.6	Sand and Gravel

Culvert Site No.	Borehole No.	Top of Layer (below topsoil/pavement surface)		Bottom of Layer		Thickness (m)	Fill Type
		Depth (m)	Elevation (m)	Depth (m)	Elevation (m)		
	326-4	0.1	175.0	0.6	174.5	0.5	Clayey Silt
		0.6	174.5	1.4	173.7	0.8	Sandy Gravel
		1.4	173.7	2.2	172.9	0.8	Organic Clayey Silt
		2.2	172.9	3.7*	171.4*	1.5*	Gravel and Cobbles
	1	0.0	174.8	1.7	173.1	1.7	Clayey Silt
34-458/C	458-2	0.0	179.6	0.7	178.9	0.7	Silty Gravelly Sand
	458-3	0.0	179.5	1.5	178.0	1.5	Sand and Gravel

*Borehole terminated within this deposit due to casing refusal on cobbles.

The SPT “N”-values measured within the granular fill layers range from 5 blows to 38 blows per 0.3 m of penetration, indicating a loose to dense compactness condition. The SPT “N”-values measured within the cohesive fill layers in the boreholes advanced during the current investigation range from 5 blows to 12 blows per 0.3 m of penetration, suggesting a firm to stiff consistency. The SPT “N”-value measured in the fill in Borehole 1 (from the previous investigation) was 49 blows per 0.3 m of penetration; however, this value may not be representative of the deposit as the Record of Borehole 1 indicates that occasional rock fragments were noted, which may have affected the SPT result.

Grain size distribution tests were carried out on five samples from the silty gravelly sand to sand and gravel to sandy gravel fill layers and the results are shown on Figure A-1 Appendix A. The water content measured on eight samples of the granular fill ranges between about 3 per cent and 13 per cent.

Grain size distribution tests were carried out on three samples from the gravelly silty clay to silty clay fill layers and the results are shown on Figure A-2 Appendix A. Atterberg limits tests were carried out on two samples of the gravelly silty clay and silty clay fill and measured liquid limits of about 37 per cent and 44 per cent, plastic limits of about 18 per cent and plastic indices of about 19 per cent and 26 per cent. The results, which are plotted on the plasticity chart on Figure A-3 in Appendix A, indicate that the cohesive fill consists of silty clay of medium plasticity.

The water content measured on four samples of the cohesive fill ranges from about 15 per cent to 22 per cent. One organic content test was completed on a sample of the organic clayey silt fill from Borehole 326-4 and the result is 6.9 per cent.

4.2.1.4 Upper Silty Clay to Clay (Crust)

An upper brown and grey, silty clay to clay, trace sand (crust) was encountered below the fill in Boreholes 458-2 to 458-3 and below the topsoil in Boreholes 458-1 and 458-4 at depths of between about 0.1 m and 1.5 m below ground surface (between Elevations 179.2 m and 178.0 m). The upper silt clay to clay crust extends to depths of between about 3.7 m to 4.4 m below ground surface (between Elevations 175.9 m and 174.3 m). In Borehole 458-1, between a depth of 3.8 m and 4.4 m below ground surface, the clay deposit was varved.

SPT “N”-values within the upper silty clay to clay crust range from 5 blows to 26 blows per 0.3 m of penetration, suggesting a firm to very stiff consistency.

Grain size distribution tests were carried out on six selected samples of the silty clay to clay deposit from the current investigation and the results are shown in Figure A-4 in Appendix A. Atterberg limits testing was carried out on six samples of the silty clay to clay deposit and measured liquid limits ranging from about 47 per cent to 58 per cent, plastic limits ranging from about 21 per cent to 26 percent, and plasticity indices ranging from about 24 per cent to 34 per cent. These results, which are plotted on a plasticity chart on Figure A-5 in Appendix A, indicate that the upper cohesive deposit consists of silty clay of medium plasticity to clay of high plasticity.

The water content measured on 9 samples of the silty clay to clay deposit ranges between about 22 per cent and 33 per cent.

4.2.1.5 Lower Clayey Silt to Silty Clay

At Culvert Site No. 34-326/C a deposit consisting of clayey silt, trace to some sand, trace to some gravel, was encountered underlying the fill in Boreholes 326-1, 326-2, 326-3, and Borehole 1 from the previous investigation, at depths ranging from 4.1 m to 7.3 m below ground surface (between Elevations 171.0 m and 170.7 m). The surface of the deposit was encountered in Borehole 1 at a depth of 1.7 m below ground surface (Elevation 173.1 m). Organic material, including wood chips, was encountered in Borehole 1 between depths of 1.7 m and 3.0 m below ground surface (between Elevations 173.1 m and 171.8 m) and from a depth of 18.3 m and the end of the borehole, 75 mm thick layers of silt were noted to have been encountered during the previous investigation. Borehole 1 terminated in this clayey silt deposit at a depth of 20.7 m below ground surface (Elevation 154.1 m). Boreholes 326-1, 326-2 and 326-3 were terminated within the clayey silt deposit at depths ranging between 6.7 m and 17.4 m below ground surface (between Elevations 168.4 m and 160.5 m).

At Culvert Site No. 34-458/C a lower deposit consisting of clayey silt to silty clay, trace sand, trace gravel, was encountered underlying the upper silty clay to clay crust in Boreholes 458-1 to 458-4 at depths of between 3.7 m to 4.4 m below ground surface (between Elevations 175.9 m and 174.3 m). All of these boreholes terminated within the clayey silt to silty clay deposit, at depths ranging between 14.9 m and 17.4 m below ground surface (between Elevations 164.4 m and 162.1 m). In Borehole 458-1 at a depth of 14.3 m, sandy silt pockets were noted within the clayey silt deposit. In Borehole 458-3, rootlets were noted at a depth of about 7.9 m below ground surface (Elevation 171.6 m).

SPT “N”-values within the clayey silt to silty clay deposit range from weight of hammer to 21 blows per 0.3 m of penetration. In-situ vane tests carried out within the cohesive deposit measured undrained shear strengths ranging from about 34 kPa to about 61 kPa, with two values greater than 95 kPa, with a calculated sensitivity ranging between about 1.1 and 3.2. The field vane test results together with the SPT “N” values indicate that the clayey silt to silty clay deposit has a firm to very stiff consistency. In Borehole 1 the SPT “N”-values within the clayey silt deposit below a depth of about 18.3 m below ground surface (Elevation 156.5 m) were 60 blows and 120 blows per 0.3 m of penetration, suggesting a hard consistency below Elevation 156.5 m to the end of the borehole at Elevation 154.1 m.

Grain size distribution tests were carried out on thirteen samples of the clayey silt to silty clay deposit from the current investigation and the results are shown in Figures A-6A (for Culvert Site No. 34-326/C) and A-6B (for Culvert Site No. 34-458/C) in Appendix A. Atterberg limits testing was carried out on thirteen samples of the clayey silt to silty clay deposit and measured liquid limits ranging from about 23 per cent to 37 per cent, plastic limits ranging from about 14 per cent to 20 per cent, and plasticity indices ranging from about 9 per cent to 18 per cent. These results, which are plotted on a plasticity chart on Figures A-7A (for Culvert Site No. 34-326/C) and A-7B (for Culvert Site No. 34-458/C) in Appendix A, indicate that the cohesive deposit consists of clayey silt of low plasticity to silty clay of medium plasticity.

The water content measured on 26 samples of the clayey silt to silty clay to clay deposit ranges between about 16 per cent and 36 per cent.

4.2.1.6 Groundwater Conditions

Details of the water levels observed in the open boreholes at the time of drilling are presented on the Records of Borehole sheets in Appendix A. A standpipe piezometer was installed in Boreholes 326-1 and 458-4 to monitor the groundwater level at the borehole locations. The water levels measured in the open boreholes and the piezometers are summarized below. It should be noted that the groundwater level in the area is subject to seasonal fluctuations and precipitation events and should be expected to be higher during wet periods of the year.

<table>
<tr><th>Borehole No.</th><th>Ground Surface Elevation (m)</th><th>Depth to Water Level (m)</th><th>Groundwater Elevation (m)</th><th>Date</th><th>Comments</th></tr>
<tr><td rowspan="4">326-1</td><td rowspan="4">175.1</td><td>2.0</td><td>173.1</td><td>January 17, 2019</td><td>Upon completion of drilling</td></tr>
<tr><td>1.2</td><td>173.9</td><td>March 20, 2019</td><td rowspan="3">Within piezometer</td></tr>
<tr><td>0.9</td><td>174.2</td><td>April 21, 2019</td></tr>
<tr><td>1.2</td><td>173.9</td><td>May 29, 2019</td></tr>
<tr><td>326-2</td><td>177.9</td><td>4.3</td><td>173.6</td><td>January 16, 2019</td><td>Upon completion of drilling</td></tr>
<tr><td>326-3</td><td>178.0</td><td>4.0</td><td>174.0</td><td>January 15, 2019</td><td>Upon completion of drilling</td></tr>
<tr><td>326-4</td><td>175.1</td><td>0.0</td><td>175.1</td><td>March 20 & 21, 2019</td><td>Water used during borehole advancement and therefore is not representative of in-situ conditions</td></tr>
<tr><td>1</td><td>174.8</td><td>1.2</td><td>173.6</td><td>December 6, 1969</td><td rowspan="3">Upon completion of drilling</td></tr>
<tr><td>458-1</td><td>178.7</td><td>Dry</td><td>-</td><td>March 20, 2019</td></tr>
<tr><td>458-2</td><td>179.6</td><td>Dry</td><td>-</td><td>January 10, 2019</td></tr>
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<table>
<tr><th>Borehole No.</th><th>Ground Surface Elevation (m)</th><th>Depth to Water Level (m)</th><th>Groundwater Elevation (m)</th><th>Date</th><th>Comments</th></tr>
<tr><td rowspan="2">458-3</td><td rowspan="2">179.5</td><td>2.8</td><td>176.7</td><td>Morning of January 9, 2019</td><td>Prior to continuing to borehole advancement</td></tr>
<tr><td>Dry</td><td>-</td><td>January 9, 2019</td><td>Upon completion of drilling</td></tr>
<tr><td rowspan="4">458-4</td><td rowspan="4">179.3</td><td>13.7</td><td>165.6</td><td>March 19, 2019</td><td>Upon completion of drilling</td></tr>
<tr><td>12.1</td><td>167.2</td><td>March 20, 2019</td><td rowspan="3">Within piezometer</td></tr>
<tr><td>8.7</td><td>170.6</td><td>April 21, 2019</td></tr>
<tr><td>8.7</td><td>170.6</td><td>May 29, 2019</td></tr>
</table>

4.2.2 Culvert Site No. 34-331/C

In general, the subsurface conditions at this culvert site consists of a layer of asphalt or topsoil underlain by fill material consisting of sand and gravel, and gravelly silty clay to sandy clayey silt. The fill is underlain by a clayey silt deposit which is further underlain by a till deposit consisting of sandy clayey silt . Limestone bedrock was encountered underlying the till deposit in both of the boreholes. A more detailed description of the subsurface conditions encountered in the boreholes and the test pit is provided in the following sections.

4.2.2.1 Asphalt

An approximately 150 mm and 130 mm thick layer of asphalt pavement was encountered at ground surface in Boreholes 331-1 and 331-2, respectively.

4.2.2.2 Topsoil

An approximately 100 mm thick layer of topsoil was encountered at ground surface in Test Pit 331-3.

4.2.2.3 Fill

A 0.4 m and 0.9 m thick layer of sand and gravel fill was encountered underlying the asphalt in Boreholes 331-1 and 331-2 at depths of 0.2 m and 0.1 m below ground surface (at Elevations 179.1 and 179.2 m, respectively). A 0.4 m and 0.5 m thick fill layer comprised of sandy clayey silt to clayey silt was encountered underlying the sand and gravel fill layer in Boreholes 331-1 and 331-2, at depths of about 0.6 m and 1.0 m below ground surface (Elevations 178.7 m and 178.3 m, respectively). Test Pit 331-3 encountered fill consisting of gravelly silty clay with sand underlying the topsoil and the test pit terminated in the fill at a depth of 0.2 m below ground surface (Elevation 178.7 m).

A SPT “N”-value of 16 blows per 0.3 m of penetration was recorded in the clayey silt fill layer, and a SPT “N”-value of 12 blows per 0.3 m of penetration was recorded at the transition between the sandy clayey silt fill layer and the underlying clayey silt, suggesting a stiff to very stiff consistency.

Grain size distribution testing was carried out on one sample of the gravelly silty clay with sand fill material from Test Pit 331-3 and the result is presented on Figure B-1 in Appendix B. Atterberg limits testing was carried out on one sample from the gravelly silty clay with sand fill layer and measured a liquid limit of about 40 per cent, a plastic limit of about 25 per cent, and a plasticity index of about 15 per cent. These results, which are plotted on a plasticity chart on Figure B-2 in Appendix B, indicate that the gravelly clayey silt with sand fill material from Test Pit 331-3 consists of silty clay of medium plasticity.

The water content measured on two samples of the sand and gravel fill ranges between about 5 per cent and 22 per cent. The water content measured on two samples of the sandy clayey silt and gravelly silty clay with sand fill are about 19 per cent and 22 per cent.

4.2.2.4 Clayey Silt

An approximately 3.2 m and 2.2 m thick cohesive deposit comprised of clayey silt, trace sand, trace gravel with silt pockets and sand pockets was encountered underlying the fill in Boreholes 331-1 and 331-2, respectively at depths of 1.0 m and 1.5 m below ground surface (at Elevations 178.3 m and 177.8 m) and extends to depths of 4.2 m and 3.7 m below ground surface (Elevations 175.1 m and 175.6 m).

The SPT "N"-values measured within the clayey silt deposit range from 11 blows to 22 blows per 0.3 m of penetration, suggesting a stiff to very stiff consistency.

Grain size distribution testing was carried out on one sample of the clayey silt deposit and the result is shown on Figure B-3, in Appendix B. Atterberg limits testing was carried out on two samples of the clayey silt deposit and measured liquid limits of about 31 per cent and 32 per cent, plastic limits of about 16 per cent, and plasticity indices of about 15 per cent and 16 per cent. These results, which are plotted on a plasticity chart on Figure B-4 in Appendix B, indicate that the deposit consists of clayey silt of low plasticity.

Water content measured on two samples of the clayey silt deposit are approximately 15 per cent and 16 per cent.

4.2.2.5 Sandy Clayey Silt (Till)

An approximately 0.1 m and 0.7 m thick glacial till deposit comprised of sandy clayey silt, trace gravel was encountered underlying the clayey silt deposit in Boreholes 331-1 and 331-2 respectively at depths of 4.2 m and 3.7 m below ground surface (at Elevations 175.1 m and 175.6 m) and extends to depths of 4.3 m and 4.4 m below ground surface (Elevations 175.0 m and 174.9 m).

A SPT "N"-value of 16 blows per 0.3 m of penetration was recorded in the till deposit, suggesting a very stiff consistency.

Grain size distribution testing was carried out on one sample of the till deposit and the result is shown on Figure B-5, in Appendix B. Atterberg limits testing was carried out on one sample of the cohesive till deposit and measured a liquid limit of about 22 per cent, a plastic limit of about 13 per cent, and a plasticity index of about 9 per cent. The result, which is plotted on a plasticity chart on Figure B-6 in Appendix B, indicates that the cohesive deposit consists of clayey silt of low plasticity.

Water content measured on two samples of the cohesive till deposit are approximately 12 per cent and 13 per cent.

4.2.2.6 Limestone Bedrock

Bedrock was confirmed by bedrock coring in Boreholes 331-1 and 331-2. The depths to bedrock below ground surface and the corresponding bedrock surface elevations are summarized below:

Borehole No.	Ground Surface Elevation (m)	Depth to Bedrock Surface (m)	Bedrock Surface Elevation (m)	Comments
331-1	179.3	4.3	175.0	Bedrock coring for 3.18 m
331-2	179.3	4.4	174.9	Bedrock coring for 3.01 m

Based on a review of the bedrock core samples, the bedrock consists of limestone of the Onondaga Formation. In general, the bedrock core samples are described as fresh, thinly bedded, grey, very fine grained to fine grained, non-porous to faintly porous, strong limestone, as presented on the Record of Drillhole sheets in Appendix B, and as shown on the photographs of the recovered core samples on Figure B-7 in Appendix B. The degree of weathering of the bedrock core samples (i.e., fresh – W1), and the strength classification of the intact rock mass based on field identification (i.e., strong – R4) are described in accordance with the International Society for Rock Mechanics (ISRM[5]) standard classification system.

The Rock Quality Designation (RQD) measured on the core samples ranges from about 84 per cent to 98 per cent, indicating a rock mass of good to excellent quality as per Table 3.10 of CFEM (2006)[6]. The Total Core Recovery (TCR) and Solid Core Recovery (SCR) of samples recovered range between 99 per cent and 100 per cent and between 91 per cent and 98 per cent, respectively.

Unconfined Compression (UC) testing (ASTM D7012)[7] was carried out on two selected core samples of the limestone bedrock and the uniaxial compressive strength (UCS) of the intact samples are summarized below and are presented on Figures B-8A, B-8B, B-9A and B-9B in Appendix B. The UCS of the intact limestone rock specimens was 72.4 MPa and 74.5 MPa in Boreholes 331-1 and 331-2, respectively, which is classified as strong rock (R4, 50 MPa < UCS < 100 MPa).

Borehole No.	Sample Depth (m)	Sample Elevation (m)	UCS (MPa)	Bedrock Type
331-1	4.29 – 4.48	175.01 – 174.82	72.4	Limestone
331-2	6.02 – 6.22	173.28 – 173.08	74.5	Limestone

4.2.2.7 Groundwater Conditions

Details of the water levels observed in the open boreholes at the time of drilling are presented on the Record of Borehole sheets in Appendix B. Boreholes 331-1 and 331-2 were both dry upon completion of soil drilling. It should

[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.

[6] Canadian Geotechnical Society, 2006. Canadian Foundation Engineering Manual (CFEM), 4th Edition. The Canadian Geotechnical Society, BiTech Published Ltd., British Columbia.

[7] ASTM D7012 – Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens

be noted that the groundwater level in the area is subject to seasonal fluctuations and precipitation events and should be expected to be higher during wet periods of the year.

4.3 Analytical Testing Results

Six soil samples were submitted for analysis of parameters used to assess the potential corrosivity of the soil to steel and concrete at the three culvert sites. The following summarizes the results of the testing:

Parameter	Culvert Site No. 34-326/C		Culvert Site No. 34-458/C		Culvert Site No. 34-331/C	
	Borehole 326-2 SA#3 Silty Clay Fill	Borehole 326-3 SA#4 Silty Clay Fill	Borehole 458-2 SA#5 Clayey Silt to Silty Clay	Borehole 458-3 SA#6 Clayey Silt to Silty Clay	Borehole 331-1 SA#4 Clayey Silt	Borehole 331-2 SA#5 Sandy Clayey Silt (Till)
pH	7.70	7.73	7.83	7.78	7.82	7.81
Resistivity (ohm-cm)	670	1,000	430	1,300	700	3,200
Electrical Conductivity (umho/cm)	1,490	966	2,340	794	1,420	312
Chlorides (ug/g)	410	76	58	330	710	82
Soluble Sulphates (ug/g)	830	810	3,600	220	120	61

5.0 CLOSURE

This report was prepared by Ms. Katelyn Nero, a geotechnical Engineer-In-Training with Golder and reviewed by Ms. Sandra McGaghran, M.Eng., P.Eng., an Associate and Senior Geotechnical Engineer with Golder. Mr. Paul Dittrich, Ph.D., P.Eng., a Principal with Golder and an MTO Foundations Designated Contact, conducted a technical and quality control review of the report.

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PART B

FOUNDATION DESIGN REPORT

CULVERT REPLACEMENTS, STRUCTURE NOS. 34-326/C, 34-331/C AND 34-458/C

HIGHWAY 3 AND HIGHWAY 140, NIAGARA REGION

MTO, G.W.P. 2374-15-00

6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS

This section of the report provides foundation design recommendations for the replacement or rehabilitation of the following three structural culverts in the Region of Niagara:

- Culvert Site No. 34-326/C, Highway 140, At Lyons Creek, City of Welland
- Culvert Site No. 34-331/C, Highway 3, West of White Road, City of Port Colborne
- Culvert Site No. 34-458/C, Highway 140, North of Highway 58A, City of Port Colborne

These recommendations are based on interpretation of the factual data obtained from the boreholes and test pit advanced during the subsurface investigation. The discussion and recommendations presented are intended to provide the designers with sufficient information to assess the feasible foundation alternatives and carry out the design of the culvert foundations, and to provide the designers with sufficient information to assess the feasible temporary protection system alternatives. The foundation investigation report, discussion and recommendations are intended for the use of MTO and its designers and shall not be used or relied upon for any other purpose or by any other parties, including the construction or design-build contractor. The contractor must make their own interpretation based on the factual data presented in the Part A (Foundation Investigation) of the report. Where comments are made on construction, they are provided to highlight those aspects that could affect the design of the project and for which special provisions may be required in the Contract Documents. Those requiring information on aspects of construction must make their own interpretation of the factual information provided as such interpretation may affect equipment selection, proposed construction methods, scheduling and the like.

6.1 General

Plan and profiles drawings for the culvert sites, were provided to Golder by AIA on April 16, 2019. An updated General Arrangement Drawing of Culvert Site No. 34-326/C was provided to Golder on May 23, 2019, and indicates this culvert is to be rehabilitated instead of replaced with a new culvert. An updated General Arrangement Drawing of Culvert Site No. 34-458/C was provided to Golder on June 11, 2019, and indicates this culvert is also to be rehabilitated instead of replaced with a new culvert. The following summarizes the details regarding the existing culverts and proposed replacement/rehabilitated culverts:

Site No. / Culvert Location	Existing Structure	Proposed Structure Dimensions[1]	Approximate Existing Maximum Embankment Height[2] (m)	Proposed Culvert Invert Elevation (m)	
				U/S	D/S
34-326/C Highway 140, At Lyons Creek	3.3 m wide corrugated steel arch culvert	Rehabilitated with a 2800 mm × 1950 mm corrugated steel arch pipe grouted into existing culvert (38 m long)	2.5	173.5	172.9

Site No. / Culvert Location	Existing Structure	Proposed Structure Dimensions[1]	Approximate Existing Maximum Embankment Height[2] (m)	Proposed Culvert Invert Elevation (m)	
				U/S	D/S
34-331/C Highway 3, West of White Road	3.5 m wide open-footing reinforced concrete rigid frame box culverts that provide extensions at each end of an older 3.5 m wide open-footing reinforced concrete arch culvert	5580 mm wide x 2270 mm high Concrete Box Culvert (15 m long)	0.9	176.9	176.8
34-458/C Highway 140, North of Highway 58A	3.8 m wide corrugated steel arch culvert	Rehabilitated with a 3100 mm × 1980 mm corrugated steel arch pipe grouted into existing culvert (33 m long)	2.5	175.0	174.9

Notes:
1. Interior dimension.
2. Maximum embankment height above top of culvert and above average surrounding natural ground surface.

It is understood that the existing culverts are to be either replaced with a new culvert on the same alignment as the existing, or are to be rehabilitated with a liner. Temporary protection systems will be required to support the existing roadway and to accommodate the proposed traffic staging plans during construction wherever a full culvert replacement is carried out (i.e. at Culvert Site No. 34-331/C). The installation of temporary protection systems is not anticipated to be required where the existing culverts are rehabilitated by lining (i.e. at Culvert Site Nos. 34-326/C and 34-458/C).

6.2 Consequence and Site Understanding Classification

In accordance with Section 6.5 of the *Canadian Highway Bridge Design Code* and its *Commentary* (CHBDC, 2014), the proposed culvert foundation systems at each site are classified as having a "typical consequence level" associated with exceeding limits states design. In addition, given the level of foundation investigation completed to date at these locations in comparison to the degree of site understanding in Section 6.5 of the CHBDC (2014), the level of confidence for foundation design of the culverts is considered to be a "typical degree of site and prediction model understanding." Accordingly, the appropriate corresponding ULS and SLS consequence factor, ψ, from Table 6.1 and geotechnical resistance factors, ϕ_{gu} and ϕ_{gs}, from Table 6.2 of the CHBDC (2014) have been used for design.

6.3 Seismic Design

6.3.1 Seismic Site Classification

Subsurface ground conditions for seismic site characterization were established based on the results of the field investigation. The SPT "N'-values, undrained shear strengths (s_u), and estimated shear wave velocity for the bedrock (where applicable) for a depth of 30 m below the founding levels were used to estimate the seismic site classification in accordance with Table 4.1 of the CHBDC (2014). Based on this methodology, and in the absence of any geophysical testing, the following Site Class designations are recommended.

Site No. / Culvert Location	Seismic Site Classification
34-326/C	D
34-331/C	C
34-458/C	D

6.3.2 Spectral Response Values and Seismic Performance Category

The *CHBDC* (2014) states that the seismic hazard values associated with the design earthquakes should be those established for the National Building Code of Canada (NBCC) by the Geological Survey of Canada (GSC). The GSC has developed a new set of seismic hazard maps (referred to as the 5th generation seismic hazard maps) that were made available for public use in December 2015.

In accordance with Section 7.5.5.2 of the *CHBDC* (2014), buried structures should be designed to resist inertial forces associated with a seismic event having a 2% exceedance in 50 years (i.e., a 2,475-year return period), where the horizontal ground acceleration ratio A_H is equal to the peak ground acceleration, PGA, as specified in Section 4.4.3 of *CHBDC*. Therefore, based on Section 4.4.3 of the CHBDC and the location of the culverts, the reference Site Class C PGA values based on the 5th generation seismic hazard maps published by the GSC are as follows:

Site No. / Culvert Location	Latitude, Longitude	Seismic Hazard Values[1] PGA (g) 2% Exceedance in 50 Years (2,475-year return period)
34-326/C	42.980947, -79.204872	0.200
34-331/C	42.893553, -79.186572	0.193
34-458/C	42.961392, -79.207213	0.199

Note(s): 1. For reference Site Class C.

The PGA values given above are for the reference ground condition Site Class C and must be modified to the site-specific seismic site classification given in Section 6.3.1 (i.e., Site Class D for Culvert Site Nos. 34-326/C and 34-458/C) in accordance with Section 4.4.3.3 of the *CHBDC*. As indicated in Section 4.4.3.3 of the *CHBDC,* the value of PGA_{ref} for use with Tables 4.2 to 4.9 shall be taken as 80 per cent of the PGA for Site Class C where Sa(0.2)/PGA is less than 2.0. Based on this requirement, a PGA_{ref} value of 0.16 for the 2,475-year return was used, where required. The corresponding site-specific PGA values for the appropriate seismic site classification as given below can therefore be used for design of the culverts in accordance with Section 7.5.5.1 of the CHBDC.

Site No. / Culvert Location	Seismic Site Classification	Seismic Hazard Values PGA (g) 2% Exceedance in 50 Years (2,475-year return period)
34-326/C	D	0.235
34-331/C	C	0.193
34-458/C	D	0.234

6.4 Foundations Options - Culverts

Either box culverts or “open-footing” (shallow foundation) concrete culverts are feasible for replacement of the existing culverts. Both pre-cast concrete elements (box culvert segments or footing elements) and cast-in-place concrete elements are also feasible from a foundations perspective.

From a foundation perspective, pre-cast concrete box culverts are preferred as replacement structures for the following reasons:

- Pre-cast concrete box culvert construction minimizes the depth of excavation and groundwater control requirements as compared with open footing culverts.
- Pre-cast concrete box culvert segments can usually be installed more expeditiously than cast-in-place open footing culverts, resulting in shorter durations for dewatering, surface water pumping and traffic staging.
- Pre-cast concrete box culvert segments are more tolerant of total and differential settlement, although this is not considered a significant concern at these culvert sites.

Table 1, following the text of this report, presents an assessment of the advantages, disadvantages, relative costs and risks/consequences of the different culvert replacement/rehabilitation options for these sites.

It is noted that where new box culverts may not satisfy fisheries requirements related to channel substrate, open-footing culverts are geotechnically feasible. Recommendations for both the box culvert and open-footing options are provided in the following sections of this report.

6.5 Founding Elevations and Sub-excavation Requirements

6.5.1 Box Culverts

It is not necessary to found new box culverts at the standard depth for frost protection purposes, which at these sites is 1.2 m below adjacent final ground surface as interpolated from OPSD 3090.101 (*Frost Penetration Depths for Southern Ontario*). This is because the box structure sections are tolerant of small magnitudes of movement related to freeze-thaw cycles, should these occur. Box culverts should, however, be founded below any existing unsuitable fills, softened soils, or surficial / near surface organic materials. The following summarizes the recommended founding levels and sub-excavation requirements for new box culverts, based on the inverts of the proposed culverts noted in Section 6.1 and the base slab thicknesses from the provided GA drawings for Culvert

Site Nos. 34-326/C and 34-458/C, received April 16, 2019,of 280 mm and 300 mm, respectively. The base slab thickness at Culvert Site No. 34-331/C is 350 mm, from the updated GA drawing received on June 11, 2019.

Culvert Site No.	Proposed Underside of Culvert, Bedding Elevation (m) Upstream /Downstream	Sub-excavation Required? Inlet / Outlet	Excavation/Sub-Excavation Elevation (m) Upstream/Downstream	Subgrade Stratum below bedding material
34-326/C	173.2 / 172.6	Yes, about 0.3 m depth below the underside of the culvert to accommodate bedding material	172.9 / 172.3	Compact to dense sand and gravel to sandy gravel (Fill), underlain by firm to very stiff clayey silt.[1]
34-331/C	176.4 / 175.9		176.1 / 175.6	Stiff to very stiff clayey silt, underlain by sandy clayey silt (Till), underlain by bedrock.[2]
34-458/C	174.7 / 174.6		174.4 / 174.3	Firm to very stiff clayey silt to silty clay.[2]

Notes: 1. Proof-rolling of existing sand and gravel fill subgrade required prior to placement of new bedding material.

2. Proof-rolling of existing clayey silt to silty clay subgrade required prior to placement of new bedding material.

The box culvert founding subgrade should be inspected by geotechnical personnel to ensure that all existing topsoil and unsuitable fill/softened soils or other unsuitable materials have been removed. Proof-rolling of the subgrade will be required to identify any softened zones. Where any softened zones are present, sub-excavation is required to remove unsuitable materials, and the sub-excavated area should be backfilled with granular material meeting OPSS.PROV 1010 *(Aggregates)* Granular ‘A’ or Granular ‘B’ Type II that is placed and compacted in accordance with OPSS.PROV 501 *(Compacting)* as amended by SP 105S12. An NSSP addressing this requirement is included in Appendix D for inclusion in the Contract Documents.

The subgrade soils may be susceptible to loosening/softening and degradation on exposure to water and construction traffic. As discussed further in Section 6.13.9, if the sub-excavation backfill or bedding for the culvert is not placed within four hours after preparing the subgrade, a concrete working slab shall be placed in the excavation within four hours of exposure of the founding level to protect the integrity of the subgrade. A Non-Standard Special Provision (NSSP) to address this item is included in Appendix D, which should be included in the Contract Documents.

6.5.2 Open-Footing Culverts

Strip footings for open-footing culvert replacements should be founded at a minimum depth of 1.2 m below the lowest final adjacent surrounding grade to provide adequate protection against frost penetration, as per Ontario Provincial Standard Drawing (OPSD) 3090.101 (*Foundation, Frost Penetration Depths for Southern Ontario*). In addition, the footings should extend below any existing unsuitable fill and surficial organic materials, where present. The following summarizes the recommended founding levels and sub-excavation requirements for new open-footing culverts, based on the inverts of the proposed culverts noted in Section 6.1:

Culvert Site No.	Proposed Culvert Invert (m) Upstream / Downstream	Sub-excavation Required? Inlet / Outlet	Underside of Footing Elevation (m) Upstream / Downstream	Subgrade Stratum below strip footing bedding material [1]
34-326/C	173.5 / 172.9	No	172.3 / 171.7	Loose to dense sand and gravel to sandy gravel (Fill) underlain by firm to very stiff clayey silt[1]
34-331/C	176.9 / 176.8		175.7 / 175.6	Stiff to very stiff clayey silt, underlain by sandy clayey silt (Till), underlain by bedrock [2]
34-458/C	175.0 / 174.9		173.8 / 173.7	Firm to very stiff clayey silt to silty clay[2]

Notes:
1. Proof-rolling of existing sand and gravel fill subgrade required prior to construction of the footing.
2. Proof-rolling of native clayey silt subgrade required prior to construction of the footing.

The footing subgrade should be inspected following excavation, in accordance with OPSS 902 *(Excavating and Backfilling Structures)*, as amended by SP 109S12, to check that any existing unsuitable fill and organic soils or other unsuitable material have been removed. Proof-rolling of the footing subgrade will be required to identify any softened zones. Where any softened zones are present, sub-excavation is required to remove unsuitable materials, and the sub-excavated area should be backfilled with granular material meeting OPSS.PROV 1010 *(Aggregates)* Granular 'A' or Granular 'B' Type II that is placed and compacted in accordance with OPSS.PROV 501 *(Compacting),* as amended by SP 105S12. An NSSP addressing this requirement is included in Appendix D for inclusion in the Contract Documents.

The footing subgrade at all sites will be susceptible to loosening/softening and degradation on exposure to water and construction traffic. As discussed further in Section 6.13.9, if the footings are not constructed within four hours after preparing the subgrade a concrete working slab should be placed to protect the integrity of the subgrade. An example NSSP for the working slab is included in Appendix D and should be included in the Contract Documents.

6.6 Geotechnical Resistance

6.6.1 Box Culverts

Box culverts constructed on compacted bedding placed on the compact existing fill or native soil deposits (generally a stiff to very stiff clayey silt to silty), and founded at or below the design elevations given in the Section 6.5.1, may be designed based on the factored ultimate geotechnical resistances and factored serviceability geotechnical resistances (for 25 mm of settlement) given below.

Culvert	Founding Stratum	Factored Ultimate Geotechnical Resistance	Factored Serviceability Geotechnical Resistance (for 25 mm of settlement)
34-326/C	Compacted Granular A bedding on: - Compact to dense sand and gravel to sandy gravel (Fill) - Firm to very stiff clayey silt	300 kPa	125 kPa
34-331/C	Compacted Granular A bedding on: - stiff to very stiff sandy clayey silt to clayey silt (Till)	350 kPa	250 kPa
34-458/C	Compacted Granular A bedding on: - firm to very stiff clayey silt to silty clay	150 kPa	100 kPa

The geotechnical resistances and settlements are dependent on the box culvert span, configuration and applied loads, including the loads imparted by the embankment reconstruction; the above geotechnical resistances therefore, must be reviewed if the culvert span/footing size or founding elevation differs significantly from that given above. In addition, the geotechnical resistances, must be revised if there are any grade raises at the culvert sites or if there is any embankment widening to accommodate traffic staging and/or road widening. The geotechnical resistances provided above are based on loading applied perpendicular to the surface of the footings. Where the load is not applied perpendicular to the surface of the footing, inclination of the load should be taken into account in accordance with Section 6.10.4 of the Canadian Highway Bridge Design Code (CHBDC) (2014).

6.6.2 Open-Footing Culverts

Strip footings placed on the properly prepared subgrade at or below the founding elevations recommended in Section 6.5.2, should be designed based on the factored ultimate geotechnical resistance values and the factored serviceability geotechnical resistance values (for 25 mm of settlement) as given below. These recommendations are based on an assumed footing width of 1 m.

Culvert Site No.	Founding Stratum	Factored Ultimate Geotechnical Resistance	Factored Serviceability Geotechnical Resistance (for 25 mm of settlement)
34-326/C	Loose to dense sand and gravel to sandy gravel (Fill).	170 kPa	--[1]
34-331/C	Stiff to very stiff sandy clayey silt to clayey silt (Till)	300 kPa	--[1]
34-458/C	Firm to very stiff clayey silt to silty clay	150 kPa	--[1]

Note:

1. The factored serviceability geotechnical resistance (for 25 mm of settlement) is equal to or greater than the factored ultimate geotechnical resistance, and therefore the factored ultimate geotechnical resistance should be used in design.

The geotechnical resistances and settlements are dependent on the footing size, configuration and applied loads, including the loads imparted by the existing embankment construction; the geotechnical resistances/reactions, therefore, must be reviewed if the footing size or founding elevation differs significantly from that given above. In addition, the geotechnical resistances, must be revised if there are any grade raises at the culvert sites or if there is any embankment widening to accommodate traffic staging and/or road widening. The geotechnical resistances provided above are based on loading applied perpendicular to the surface of the footings. Where the load is not applied perpendicular to the surface of the footing, inclination of the load should be taken into account in accordance with Section 6.10.4 of the CHBDC (2014).

6.7 Resistance to Lateral Loads / Sliding Resistance

Resistance to lateral forces / sliding resistance between the precast base slab or cast-in-place footings for the new culverts and the subgrade should be calculated in accordance with Section 6.10.5 of the CHBDC (2014). The coefficient of friction, tan δ, (unfactored) that may be used for design at each site is provided below.

Culvert Site No.	Founding Stratum	Coefficient of friction, tan δ (unfactored)
34-326/C	Compacted Granular 'A' bedding on compact sand and gravel fill	0.70
	Cast-in-Place Concrete Footings on compact sand and gravel fill	0.60
34-331/C	Compacted Granular 'A' bedding on stiff to very stiff clayey silt	0.50
	Cast-in-Place Concrete Footings on stiff to very stiff clayey silt	0.45
34-458/C	Compacted Granular 'A' bedding on firm to very stiff clayey silt to silty clay	0.50
	Cast-in-Place Concrete Footings on stiff to very stiff clayey silt	0.45
34-326/C, 34-331/C, and 34-458/C	Precast Concrete Culverts on compacted Granular 'A' Bedding	0.45

6.8 Culvert Bedding, Cover, and Backfill

For the new box culverts, the bedding/levelling course and backfill requirements should be in accordance with OPSS 422 (*Precast Reinforced Concrete Box Culverts and Box Sewers in Open Cut*). New box culverts should be provided with at least 300 mm thick of OPSS.PROV 1010 (*Aggregates*), Granular 'A' material for bedding purposes, or alternatively a 100 mm thick concrete working slab. The levelling course may consist of OPSS.PROV 1010 (*Aggregates*), Granular 'A' or OPPS.PROV 1002 (*Aggregates - Concrete*) Fine Aggregate.

Granular bedding is not required for footings for open-footing culverts. Footings can be placed directly on properly prepared subgrade, as described in Section 6.5.2.

Culvert construction, backfill and cover for all concrete culverts (either box culvert or open-footing) should be completed in accordance with OPSD 803.010 (*Backfill and Cover for Concrete Culverts*), including the placement of a 75 mm thick levelling course. Backfill to culvert walls and cover should consist of granular fill meeting the requirements of OPSS.PROV 1010 (*Aggregates*), Granular 'A' or Granular 'B' Type II. The backfill and cover should be placed and compacted in accordance with OPSS.PROV 501 (*Compacting*), as amended by SP 105S22. The new culverts should be designed for the full overburden and hydrostatic pressures, and live load, assuming that the embankment fill has a unit weight of 22 kN/m^3 for OPSS.PROV 1010 (*Aggregates*) Granular 'A', 21 kN/m^3 for Granular 'B' Type II and 19 kN/m^3 for earth fill above the cover comprised of Granular 'B' Type I, Select Subgrade Material (SSM) or earth borrow.

It is not recommended to reuse the silty clay to clay from Culvert Site No. 34-458/C for backfill material above the culvert or as part of the embankment reconstruction due to its high plasticity. A Notice to Contractor addressing this restriction is included in Appendix D for inclusion in the Contract Documents. Excavated granular fill material or clayey silt fill from the existing embankments may be used to backfill above the culvert cover within the footprint of the existing highway embankment. Excavated granular fill material or clayey silt should meet the specifications for suitable earth borrow material as per OPSS.PROV 212 (*Earth Borrow*) and in accordance with OPSS.PROV 206 (*Grading*) and be placed and compacted in accordance with OPSS.PROV 501 (*Compacting*), as amended by SP 105S22. The existing fill material from above the groundwater level is expected to near its optimum moisture content for compacting. Fill material from below the groundwater level will likely require drying in order to reach optimum moisture content, prior to placement and compaction.

Backfill placement for the reconstruction of the roadway embankments placed along and over the culverts should be carried out as per OPSD 208.010 (*Benching of Earth Slopes*) to integrate the existing embankment fill and the new fill along the embankment excavation/cut faces.

6.9 Embankment Stability and Settlement

It is understood that widening of the highway or raising of the grade is not required as part of the culvert rehabilitation/replacement at the three sites and therefore settlement is not anticipated and the restored embankment side slopes will essentially match the side slopes of the existing highway embankment, which were constructed at an inclination of about 2 horizontal to 1 vertical (2H:1V), based on the survey information provided by AIA. Observations of the embankment side slopes at the time of the borehole investigation, indicate that the side slopes appear to be performing adequately with no visual evidence of seepage, surficial sloughing or slope instability.

6.9.1 Methodology

Limit equilibrium slope stability analyses were performed for the existing embankments at each of the culvert locations using the commercially available program Slide (Version 2018) produced by Rocscience Inc., employing the Morgenstern-Price method of analysis. Morgenstern Price is a general method of slices which is based on equilibrium of forces and moments acting on each slice of soil mass above the potential failure surface. For all analyses, the Factor of Safety (FoS) of numerous potential failure surfaces was computed in order to establish the minimum FoS. The FoS is defined as the ratio of the forces tending to resist failure to the driving forces tending to cause failure. For the purpose of the stability analysis, the Factor of Safety is equal to the inverse of the product of the consequence factor, Ψ, and the geotechnical resistance factor, ϕ_{gu}. (i.e., $FoS= 1/(\Psi \cdot \phi_{gu})$). A target minimum FoS of 1.33 and 1.54 is adopted for the design of embankment slopes under static conditions for the short-term/temporary condition and long-term/permanent condition, respectively as per the CHBDC (2014). The stability analyses were carried out to check that the target minimum FoS were achieved for the embankment heights and geometries considered (see Section 6.9.3).

6.9.2 Parameter Selection

For granular soils, effective stress parameters (effective friction angle and effective cohesion) were employed in the stability analyses assuming drained conditions, and were estimated from empirical correlations proposed by US Navy (1986) using the results of in situ SPTs in conjunction with engineering judgement based on experience in similar soil conditions. For the embankment fill soil the effective and total stress parameters were estimated from the results of geotechnical laboratory tests completed on similar embankment fill soil at a nearby site (Highway 140 and CNR overpass - GEOCRES 30L14-50).

For cohesive deposits, total stress parameters were employed in the embankment and founding soils assuming undrained conditions to evaluate the short-term/temporary condition. The total stress parameters (i.e., average mobilized undrained shear strength, s_u) for the cohesive soils were assessed based on the results of in situ field vane shear tests, estimated from correlations with the SPT results, and other laboratory test data where appropriate and in conjunction with engineering judgement based on experience in similar soil conditions. For the long-term permanent condition, the effective stress parameters for the cohesive deposit (including the crust) were estimated from the results of geotechnical laboratory tests completed on similar cohesive soils at a nearby site (Forkes Road East and the Welland Canal, which is west of Highway 140 and south of Culvert Site No. 34-458/C) (GEOCRES 30L14-005).

For the purpose of the stability analyses, the following details the groundwater elevation for each of the culvert sites. The groundwater level used in the analyses for Culvert Site Nos. 34-326/C is based on the highest piezometric groundwater level measured in monitoring well installed Borehole 326-1. At Culvert Site No. 34-331/C the boreholes were dry upon completion of drilling, and so the 50-year high water level as shown on the General Arrangement drawing provided by AIA in June 2019, has been employed in the analysis which is conservative and not necessarily representative of typical conditions. For Culvert Site No. 34-458/C the water level measured in the monitoring well installed in Borehole 458-4 was about 4.4 m below the invert of the culvert; however, Borehole 458-4 was advanced north of the site and the water level may not be reflective of the groundwater conditions at the culvert. For the purposes of the slope stability analyses for Culvert Site No. 34-458/C it is assumed that the water level is at the invert of the culvert. The groundwater elevation assigned in the stability analysis for each site is summarized below.

Culvert Site No.	Groundwater Elevation used in Slope Stability Analyses (m)
34-326/C	174.2
34-331/C	178.3
34-458/C	175.0

The simplified stratigraphy together with the associated unit weights and foundation engineering parameters employed for the culvert sites are presented in the tables shown on the results of stability analyses, on Figures 1A to 3B.

6.9.3 Results of Stability Analyses

The results of the global slope stability analyses indicates that the existing slope configuration for all three culvert sites have a FoS of greater than 1.54 for the short-term and long-term conditions (see Figures 1A to 3B). It is noted that surficial stability of the embankment side slopes at all three culvert sites is less than the FoS of 1.54, but generally greater than 1.2. Erosion protection and on-going maintenance of the slope may be required, depending on the embankment fill type(s) and surface treatments. Further discussion on these aspects is provided in Section 6.13.2.

6.10 Culvert Erosion Protection

Provision should be made for scour and erosion protection at the inlets and outlets at the culvert sites. In order to prevent surface water from flowing either beneath the culvert (i.e., in the case of box culverts), potentially causing undermining and scouring, or around the culvert, creating seepage through the embankment fill and potentially causing erosion and loss of fine soil particles, a clay seal or concrete cut-off wall should be provided at the upstream and downstream end of each culvert. If a clay seal is adopted, the clay material should meet the requirements of OPSS.PROV 1205 (Clay Seal), and the seal should extend from a depth of 1 m below the scour level to a minimum horizontal distance of 2 m on either side of the culvert inlet openings, and a minimum vertical height equivalent to the high water level including along the embankment slopes.

If the creek flow velocities are sufficiently high, provision should be made for scour and erosion protection (suitable non-woven geotextiles and/or rip-rap) at the culvert inlets and outlets, including in front of any wing walls/retaining walls adjacent to the channels. The requirements for and design of erosion protection measures for the inlet and outlet of the culverts should be assessed by the hydraulic design engineer. As a minimum, rip-rap treatment for the outlet of the culverts should be consistent with the standard presented in OPSD 810.010 (Rip-Rap Treatment) using OPSS.PROV 1004 (Aggregates – Miscellaneous) R-10 or R-50 size rip-rap material as may be required by the hydraulic design engineer. Erosion protection for the inlet of the culverts should also follow the standard presented in OPSD 810.010 (Rip-Rap Treatment) similar to the outlet, but the rip-rap should be placed up to the toe of slope level, in combination with the cut-off measures noted above.

6.11 Lateral Earth Pressures for Design of Culvert Walls

The lateral earth pressures acting on the culvert walls will depend on the type and method of placement of the backfill materials, the nature of the soils behind the backfill, the magnitude of surcharge including construction loadings, the freedom of lateral movement of the structure, and the drainage conditions behind the walls. Seismic (earthquake) loading must also be taken into account in the design.

The following recommendations are made concerning the design of the culvert walls:

- Free-draining granular fill meeting the specifications of OPSS.PROV 1010 (*Aggregates*) Granular ‘A’ or Granular ‘B’ Type II, should be used as backfill behind the culvert walls. Compaction (including type of equipment, target densities, etc.) should be carried out in accordance with OPSS.PROV 501 (*Compacting*) as amended by SP 105S22. Other aspects of the granular backfill requirements with respect to frost taper should be in accordance with OPSD 803.010 (*Backfill and Cover for Concrete Culverts*).
- A minimum compaction surcharge of 12 kPa should be included in the lateral earth pressures for the structural design of the walls, in accordance with CHBDC (2014) Section 6.12.3 and Figure 6.6. Other surcharge loadings should be accounted for in the design, as required.
- For restrained walls, granular fill should be placed in a zone with the width equal to at least 1.2 m (estimated vertical frost penetration depth as interpreted from OPSD 3090.101 *(Frost Penetration Depths*)) behind the back of the wall, per Figure C6.20(a) of the *Commentary to the CHBDC (2014)*.
- For unrestrained walls, granular fill should be placed within the wedge-shaped zone defined by a line drawn at flatter than 1 horizontal to 1 vertical (1H:1V) extending up and back from the rear face of the footing in accordance with Figure C6.20(b) of the *Commentary to the CHBDC (2014)*.

6.11.1 Static Lateral Earth Pressures for Design

The following guidelines and recommendations are provided regarding the lateral earth pressures for static loading conditions. These lateral earth pressures assume that the ground above / beyond the culvert walls will be flat, not sloping. If the inclination of the slope above the wall changes then new lateral earth pressures will need to be calculated.

- For a restrained wall, the pressures are based on the existing or proposed embankment fill behind the granular backfill zone, and the following parameters (unfactored) may be used assuming the use of earth fill for the general embankment fill:

Material	Site No. 34-326/C	Site No. 34-331/C	Site No. 34-458/C
Soil Unit Weight:	19 kN/m^3	19 kN/m^3	18 kN/m^3
Coefficients of static lateral earth pressure: Active, K_a At rest, K_o	 0.44 0.61	 0.44 0.61	 0.39 0.56

- For an unrestrained wall, the pressures are based on the granular fill in the backfill zone, and the following parameters (unfactored) may be used:

Material	OPPS.PROV1010 Granular ‘A’	OPPS.PROV1010 Granular ‘B’ Type II
Soil Unit Weight:	22 kN/m^3	21 kN/m^3
Coefficients of static lateral earth pressure: Active, K_a At rest, K_o	 0.27 0.43	 0.27 0.43

- If the culvert walls allow for lateral yielding, active earth pressures may be used in the geotechnical design of the structure. The movement required to allow active pressures to develop within the backfill, and thereby assume an unrestrained structure for design, should be calculated in accordance with Section C6.12.1 and Table C6.6 of the *Commentary to the CHBDC* (2014).
- If the culvert walls do not allow for lateral yielding (i.e., restrained structure where the rotational or horizontal movement is not sufficient to mobilize an active earth pressure condition), at-rest earth pressures (plus any compaction surcharge) should be assumed for geotechnical design.

6.11.2 Seismic Lateral Earth Pressures for Design

Seismic (earthquake) loading may also be taken into account in the design of culvert walls and any wingwalls in accordance with Section 4.6.5 of the CHBDC (2014). In this regard, the following should be included in the assessment of lateral earth pressures:

- Seismic loading will result in increased lateral earth pressures acting on the culvert walls and wingwalls. The walls should be designed to withstand the combined lateral loading for the appropriate static pressure conditions given above, plus the earthquake induced dynamic earth pressure.
- In accordance with Sections 4.6.5 and C.4.6.5 of the *CHBDC (2014) and its Commentary*, for structures that allow lateral yielding, the horizontal seismic coefficient, k_h, used in the calculation of the seismic active pressure coefficient, is taken as 0.5 times the site-specific PGA. For structures that do not allow lateral yielding, k_h is taken as equal to the site-specific PGA. For both cases the value of the vertical seismic coefficient k_v is taken as zero.

- The following seismic active pressure coefficients (K_{AE}) may be used in design; these coefficients reflect the maximum K_{AE} obtained for each backfill condition and for required earthquake design period (2,475 years or 2% in 50 years) per Section 7.5.5.1 of the CHBDC (2014). It should be noted that these seismic earth pressure coefficients assume that the back of the wall is vertical and the ground surface behind the culvert wall is level. Where sloping backfill is present above / beyond the top of the wall, the lateral earth pressures under seismic loading conditions should be calculated by treating the weight of the backfill located above the top of the wall as a surcharge.

Culvert Site No. 34-326/C					
	Design Earthquake	Site PGA	Seismic Active Pressure Coefficients, K_{AE}		
			Granular 'A'	Granular 'B' Type II	Earth Fill
Yielding Wall	**2,475 Yr**	0.235g	0.37	0.35	0.55
Non-Yielding Wall	**2,475 Yr**	0.235g	0.45	0.43	0.66

Culvert Site No. 34-331/C					
	Design Earthquake	Site PGA	Seismic Active Pressure Coefficients, K_{AE}		
			Granular 'A'	Granular 'B' Type II	Earth Fill
Yielding Wall	**2,475 Yr**	0.193g	0.35	0.34	0.53
Non-Yielding Wall	**2,475 Yr**	0.193g	0.42	0.40	0.62

Culvert Site No. 34-458/C					
	Design Earthquake	Site PGA	Seismic Active Pressure Coefficients, K_{AE}		
			Granular 'A'	Granular 'B' Type II	Earth Fill
Yielding Wall	**2,475 Yr**	0.234g	0.37	0.35	0.49
Non-Yielding Wall	**2,475 Yr**	0.234g	0.45	0.43	0.60

- The K_{AE} value for a yielding wall is applicable provided that the wall can move up to $250k_h$ mm, where k_h is the site specific PGA as given in the tables for each of the culvert sites above. The displacements at each site for the design earthquakes are provided in the table below.

Culvert Site No.	Design Earthquake	Displacement (mm)
34-326/C	**2,475 Yr**	59
34-331/C	**2,475 Yr**	48
34-458/C	**2,475 Yr**	59

The earthquake-induced dynamic pressure distribution, which is to be added to the static earth pressure distribution, is a linear distribution with maximum pressure at the top of the wall and minimum pressure at its toe (i.e. an inverted triangular pressure distribution). The total pressure distribution (static plus seismic) may be determined per Section C4.6.5 of the *Commentary to CHBDC* (2014)

6.12 Analytical Testing for Construction Materials

The results of analytical tests carried out on soil samples recovered at each of the three culvert sites are presented in Sections 4.3 and on the Certificates of Analysis in Appendix C. The potential for sulphate attack and corrosion at each culvert site are discussed in the following sub-sections. However, it is ultimately up to the designer to determine the appropriate construction materials, including the exposure class and ensuring that all aspects of CSA A23.1-14 Section 4.1.1 "Durability Requirements" are followed when designing concrete elements.

6.12.1 Culvert Site No. 34-326/C

Potential for Sulphate Attack

The analytical test results were compared to CSA A23.1 14 Table 3 ("Additional requirements for concrete subjected to sulphate attack") for the potential sulphate attack on concrete. The sulphate concentrations measured in all samples of the native soils are about 0.08 per cent, which are below the exposure class of "S-3" (Moderate - 0.1 – 0.2 per cent); the sulphate concentrations are considered moderate according to the Gravity Pipe Design Guidelines Table 7.2 (MTO, 2014). Therefore, based on the samples tested, when the designer is selecting the exposure class for the structure, the effects of sulphates from within the native soil deposits around the culvert may not need to be considered.

Potential for Corrosion

Based on the test results from the soil samples the pH is about 7.7 and the resistivity values are 670 and 1,000 ohm-cm. According to the MTO Gravity Pipe Design Guidelines (2014), the pH is not considered detrimental to culvert durability. The resistivity is less than 2,000 ohm-cm, which indicates that the soil corrosiveness is generally severe (R < 2,000 ohm-cm), as per Table 3.2 of the MTO Gravity Pipe Design Guidelines (2014). As the culverts will also be located under the roadway / highway shoulders and will be exposed to de-icing salt, concrete should be designed for a "C" type exposure class as defined by CSA A23.1-14 Table 1. All culverts should be designed with consideration given to Table 7.1 of the MTO Gravity Pipe Design Guidelines (2014).

6.12.2 Culvert Site No. 34-331/C

Potential for Sulphate Attack

The analytical test results were compared to CSA A23.1 14 Table 3 ("Additional requirements for concrete subjected to sulphate attack") for the potential sulphate attack on concrete. The sulphate concentrations measured in samples of the native soils range from about 0.006 per cent to 0.01 per cent, which are below the exposure class of "S-3" (Moderate - 0.1 – 0.2 per cent); the sulphate concentrations are considered negligible according to the Gravity Pipe

Design Guidelines Table 7.2 (MTO, 2014). Therefore, based on the samples tested, when the designer is selecting the exposure class for the structure, the effects of sulphates from within the native soil deposits around the culvert may not need to be considered.

Potential for Corrosion

Based on the test results from the soil samples the pH is about 7.8 and the resistivity values are 700 and 3,200 ohm-cm. According to the MTO Gravity Pipe Design Guidelines (2014), the pH is not considered detrimental to culvert durability. The resistivity is of one sample was less than 2,000 ohm-cm, which indicates that the soil corrosiveness for this sample is generally severe (R < 2,000 ohm-cm), as per Table 3.2 of the MTO Gravity Pipe Design Guidelines (2014); however the resistivity value of the other sample tested was greater than 2,000 ohm-cm, which indicates that the soil corrosiveness is moderate. As the culverts will also be located under the roadway / highway shoulders and will be exposed to de-icing salt, concrete should be designed for a "C" type exposure class as defined by CSA A23.1-14 Table 1. All culverts should be designed with consideration given to Table 7.1 of the MTO Gravity Pipe Design Guidelines (2014).

6.12.3 Culvert Site No. 34-458/C

Potential for Sulphate Attack

The analytical test results were compared to CSA A23.1 14 Table 3 ("Additional requirements for concrete subjected to sulphate attack") for the potential sulphate attack on concrete. The sulphate concentrations measured in samples of the native soils range from about 0.02 per cent to 0.36 per cent, which at the higher end is within exposure class "S-2" (Severe - 0.2 – 2 per cent); the sulphate concentrations are considered moderate to severe according to the Gravity Pipe Design Guidelines Table 7.2 (MTO, 2014). Therefore, based on the samples tested, when the designer is selecting the exposure class for the structure, the effects of sulphates from within the native soil deposits around the culvert will need to be considered.

Potential for Corrosion

Based on the test results from the soil samples the pH is about 7.8 and the resistivity values are 430 and 1,300 ohm-cm. According to the MTO Gravity Pipe Design Guidelines (2014), the pH is not considered detrimental to culvert durability. The resistivity is less than 2,000 ohm-cm, which indicates that the soil corrosiveness is generally severe (R < 2,000 ohm-cm), as per Table 3.2 of the MTO Gravity Pipe Design Guidelines (2014). As the culverts will also be located under the roadway / highway shoulders and will be exposed to de-icing salt, concrete should be designed for a "C" type exposure class as defined by CSA A23.1-14 Table 1. All culverts should be designed with consideration given to Table 7.1 of the MTO Gravity Pipe Design Guidelines (2014).

6.13 Construction Considerations

6.13.1 Open Cut Excavations

The foundation excavations for construction of the box culverts or footings will extend through existing fill and into the underlying native soil. Groundwater was generally encountered at or below the proposed excavation depths within the fill and native soils encountered at the Culvert Site Nos. 34-331/C and 331-458/C, and above the proposed excavation at Culvert Site No. 34-326/C. Where space permits, open-cut excavations into these materials must be carried out in accordance with the guidelines outlined in the Occupational Health and Safety Act (OHSA) for Construction Activities. The existing fill materials at all three culvert sites would likely be categorized as Type 3 soil.

At Culvert Site No. 34-326/C, the native firm to stiff clayey silt would likely be categorized as Type 3 soil. At Culvert Site No. 34-331/C, the native stiff to very stiff clayey silt and stiff to very stiff sandy clayey silt till would likely be categorized as Type 3 soil. At Culvert Site No. 34-458/C, the native firm to very stiff clayey silt to silty clay would likely be categorized as Type 3 soil. Temporary excavations (i.e. those which are open for a relatively short time period) should be made with side slopes no steeper than 1 horizontal to 1 vertical (1H:1V), as outlined in OHSA. In general, depending upon the construction procedures adopted by the contractor, actual groundwater seepage conditions, the success of the contractor's groundwater control methods and weather conditions at the time of construction, some flattening and/or blanketing of the slopes may be required.

Excavated material must be stockpiled at a distance away from the excavation equal to or greater than the depth of the open cut excavation.

A Notice to Contractor is included in Appendix D to warn the contractor about the potential for encountering the limestone bedrock at Culvert Site No. 34-331/C.

6.13.2 Surficial Embankment Stability and Erosion Protection

Observations of the embankment side slopes, at the time of the borehole investigation, indicate that the side slopes at each of the culvert sites appear to be performing adequately with no visual evidence of surficial sloughing or slope instability. It is understood that the embankments will not be widened and as such the reinstated slopes will match to the existing slopes beyond the culvert inlets and outlets. The seeding of vegetation of newly reinstated embankments around the replacement culverts will promote improved surficial stability. In order to reduce erosion of the embankment side slopes due to surface water runoff, placement of topsoil and seeding or pegged sod is recommended as soon as practicable after construction of the embankments. The erosion protection must be in accordance with OPSS.PROV 804 (*Seed and Cover*). However, depending on the embankment fill material type, slope geometry, surface treatment and weather (i.e. precipitation, cycles of wetting-drying and/or freezing-thawing), surficial instability of the embankment side slopes may occur, which could include localized sloughing and erosion. As such, in order to maintain the integrity of the reinstated embankments around the inlets and outlets of the culvert replacements, erosion protection measures may be required depending on the fill type used for construction.

Based on the specified gradation, granular fill such as OPSS.PROV 1010 (*Aggregates)* Granular 'A', or Granular 'B' Type I or Type II, have a low potential for erosion. For embankments reinstated with granular fill, erosion control can be limited to hydro-seeding and vegetation. On-going maintenance for embankments constructed of this material is not expected to be required.

The specification for OPSS.PROV 1010 *(Aggregates)* SSM allows for much more variation in the gradation of the material compared to Granular 'A', or Granular 'B' Type I or Type II, and therefore has the potential to be low-erodible to moderate-erodible. Erosion protection for slopes constructed of SSM should consist of erosion control blankets and hydro-seeding. Slopes constructed of SSM and properly protected from erosion should require limited on-going maintenance.

The specification for earth borrow as provided in OPSS.PROV 212 *(Earth Borrow)* allows for a wide variability of soil types with a wide range of gradations. As such, the potential for surficial instability and erosion of earth borrow material may range from low- to severe- erodibility depending on the soils gradation. Based on the potential range in gradations, and variability and uncertainty in soil types for embankments constructed of earth borrow, flattening of side slopes may be required and robust erosion protection such as the application of a minimum 300 mm thick layer of granular sheeting meeting the specification in OPSS.PROV 1004 *(Aggregates – Miscellaneous)* is recommended to be placed on the reinstated slopes adjacent to the culvert installations. Even with appropriate erosion protection, on-going maintenance of embankment slopes at the culvert replacements constructed of earth borrow may be required depending on the side slope geometry as well as the final gradation and soil type of the earth borrow used for construction.

6.13.3 Temporary Protection Systems

It is understood that temporary excavation support systems will be used to install any replacement culverts and accommodate the traffic staging plan. The temporary excavation support systems should be designed and constructed in accordance with OPSS.PROV 539 (*Temporary Protection Systems*), as amended by SP 105S09. The lateral movement of the protection systems should meet Performance Level 2 as specified in OPSS.PROV 539 *(Temporary Protection Systems*), as amended by SP 105S09, provided that any utilities, if present, can tolerate this magnitude of deformation. The advantages, disadvantages, relative costs and risks/consequences associated with different Temporary Protection System options are compared in Table 2.

Culvert Site No. 34-326/C

It is anticipated that both a driven interlocking sheet pile system and soldier piles and lagging may be constructible where temporary protection systems are required at this site, although difficulties with installing sheet piling will likely be encountered in the eastern portion of the culvert near the outlet as casing refusal was noted at several attempts to advance a borehole in this vicinity . The sheet piles or soldier piles will need to extend to a sufficient depth to provide the necessary passive resistance for the retained soil height, plus any surcharge loads behind the protection system. Lateral support to the sheet pile wall or soldier pile wall could be provided in the form of rakers/struts or temporary anchors, if and as required. The presence of cobbles within the non-cohesive fill at this site may impede the driving of sheet piles or piles for the soldier pile and lagging system.

For the temporary protection system at Culvert Site No. 34-326/C, a design groundwater level no lower than Elevation 174.2 m should be assumed based on the groundwater level measured in the standpipe piezometer installed in Borehole 326-1. If a soldier pile and lagging system is adopted, it would be necessary to control seepage or include measures to mitigate loss of soil particles (i.e., in the granular fill) through lagging boards, such as through the use of woven geotextiles or other barriers to prevent the loss of soil.

Culvert Site No. 34-331/C

The bedrock surface is at about 1.5 m below the underside of the proposed box culvert base and about 0.5 m below the proposed open-footing culvert founding level; therefore, the use of driven sheet piles would not be feasible at this site, given the shallow depth of limestone bedrock. A till deposit consisting of sandy clayey silt was encountered overlying the shallow limestone bedrock at this site, and cobbles and/or boulders are anticipated to be encountered within the till deposit. The use of a soldier pile and lagging system may be constructible where temporary protection systems are required at this site. The contractor may elect to use a soldier pile and lagging system as sheet pile would likely be damaged if driven into the bedrock.

The soldier piles would need to extend/be socketed into the limestone bedrock to a sufficient depth to provide the necessary passive resistance for the retained soil height, plus any surcharge loads behind the protection system. Lateral support to the soldier pile wall could be provided in the form of rakers/struts or temporary anchors, if and as required.

For the temporary protection system at Culvert Site No. 34-331/C, a design groundwater level no lower than Elevation 176.9 m, or the invert of the proposed culvert replacement, should be assumed based on the less permeable soils (clayey silt) present below the depth of excavation and potential for surface water to drain towards the culvert in this low-lying area.

Culvert Site No. 34-458/C

It is anticipated that both a driven interlocking sheet pile system and soldier piles and lagging may be constructible where temporary protection systems are required at this site. The sheet piles or soldier piles will need to extend to a sufficient depth to provide the necessary passive resistance for the retained soil height, plus any surcharge loads behind the protection system. Lateral support to the sheet pile wall or soldier pile wall could be provided in the form of rakers/struts or temporary anchors, if and as required. The sheet piles or soldier pile and lagging system should be able to penetrate through the non-cohesive embankment fill layer and the firm to very stiff clayey silt deposit.

For the temporary protection system at Culvert Site No. 34-458/C, a design groundwater level no lower than Elevation 176.7 m should be assumed based on the groundwater level measured in the standpipe piezometer installed in Borehole 458-4.

While the selection and design of the temporary protection system will be the responsibility of the contractor, the following information is provided to MTO and its designers to aid in assessment of the approximate construction costs during detail design. For design considerations, the design of the excavation support system should be based on trapezoid-shaped apparent earth pressure distributions using the design parameters given below as well as applicable groundwater pressures. Where the support to the wall is provided by tiebacks or rakers/struts the wall design should be based on conventional active and passive earth pressure distributions using the design parameters given below. The tiebacks or rakers/struts must be designed to accommodate the loads applied from earth pressures, water pressures and surcharge pressures from area, line or point loads as well as the effects of sloping ground behind the system. Passive toe restraint to the soldier piles may be determined using conventional passive earth pressure distribution acting over an equivalent width equal to three times the soldier pile socket diameter provided that the soldier piles are separated by more than three times the socket diameter.

Soil Type	Unit Weight	Angle of Internal Friction	Undrained Shear Strength	Coefficient of Lateral Earth Pressure[1]		
	(γ, kN/m^3)	(ϕ, degrees)	(S_u, kPa)	Active K_a	At Rest K_o	Passive K_p [2]
Culvert Site No. 34-326/C						
Existing Sand and Gravel (Fill)	21	32	--	0.31	0.47	3.25
Existing Clayey Silt to Silty Clay to gravelly Silty Clay (Fill) (Firm to Stiff)	19	23	50	0.44	0.61	2.28
Existing Sand and Gravel to Gravel (Fill) (Compact to Dense)	21	35	--	0.27	0.43	3.69
Existing Organic Clayey Silt (Fill) (Stiff)	18	23	50	0.44	0.61	2.28

Soil Type	Unit Weight	Angle of Internal Friction	Undrained Shear Strength	Coefficient of Lateral Earth Pressure[1]		
	(γ, kN/m^3)	(ϕ, degrees)	(S_u, kPa)	Active K_a	At Rest K_o	Passive K_p [2]
Clayey Silt (Firm to Very Stiff)	18	26	40 to 60	0.39	0.56	2.56
Culvert Site No. 34-331/C						
Existing Sand and Gravel (Fill) (Compact)	21	35	--	0.27	0.43	3.69
Existing Clayey Silt to Clayey Silt with Sand (Fill) (Stiff to Very Stiff)	19	23	50	0.44	0.61	2.28
Clayey Silt (Stiff to Very Stiff)	18	26	75	0.39	0.56	2.56
Sandy Clayey Silt (Till) (Stiff to Very Stiff)	20	34	100	0.28	0.44	3.54
Culvert Site No. 34-458/C						
Existing gravelly Sand to Sand and Gravel (Fill) (Compact to Dense)	21	32	--	0.31	0.47	3.25
Silty Clay to Clay (Crust) (Firm to Very Stiff)	19	24	100	0.44	0.61	2.28
Clayey Silt to Silty Clay (Firm to Very Stiff)	18	26	40 - 60	0.39	0.56	2.56

Notes:

1. The earth pressure coefficients noted above are based on a horizontal surface adjacent to the excavation. If sloped surfaces are present, the coefficient of earth pressure should be adjusted accordingly.
2. The total passive resistance below the base of the excavation (i.e. adjacent to the temporary protection system) may be calculated based on the values of K_p indicated above but reduced by an appropriate factor that considers the allowable wall movement in accordance with Figure C6.16 of the CHBDC (2014) to account for the fact that a large strain would be required for mobilization of the full passive resistance.

It should be noted that the parameters given above are applicable to the ultimate stress condition; a stiffer design may be required than predicted by these parameters in order to maintain displacements within an acceptable range.

Depending on the time of year, there may be perched water in the fill materials. If groundwater is present it would be necessary to control seepage or include measures to mitigate loss of soil particles through lagging boards if a soldier pile and lagging system is employed.

Consideration should be given to either partial or full removal of the protection system upon completion of construction. Where possible, full removal of the protection system should be considered to mitigate potential impediments to future rehabilitation/reconstruction work. An NSSP is included in Appendix D which addressed the removal or cut-off of the protection system.

6.13.4 Temporary Cofferdam Systems - Culvert Site No. 34-326/C

At Culvert Site No. 34-326/C, the groundwater level measured in the standpipe piezometer installed in the fill and clayey silt deposits in Borehole 326-1 is at about Elevation 174.2 m, which is about 1 m to 2 m above the proposed base of the excavations, depending on the selected culvert foundation option (i.e., box culvert or open-footing). It is understood that consideration is also being given to rehabilitating this culvert instead of a full replacement. Whether the culvert is replaced or rehabilitated, Lyons Creek, which flows through Culvert Site No. 34-326/C, will be required to be diverted and as such, a temporary protection system or cofferdam will be required at the inlet and outlet of the culvert to enable the construction of the box culvert, or open-footings, or rehabilitation work to be carried out in-the-dry. Based on the anticipated ground conditions, a cofferdam consisting of a sheetpile cut-off wall installed to an appropriate depth is considered feasible at the inlet and outlet, however, the installation of sheet piles may be impeded by the presence of cobbles encountered within the granular fill adjacent to the existing culvert in Borehole 326-4 towards the outlet. Given the presence of these obstructions, consideration should be given to protecting the tips of the sheet piles and/or the use of heavier sheet pile sections and/or pre-excavation to loosen or remove the larger cobbles prior to sheet pile installation, assuming a sheet pile system is selected.

It may also be possible to construct temporary cofferdams and divert the creek water using one of the following methods:

- Small inflatable bladder cofferdams;
- Water dams consisting of industrial grade, impermeable, composite fabrics formed into flexible tubes containing one or more chambers; or,
- Multiple rows of large sand bags (“super-bags” or “bulk-bags”) lined with an impermeable layer.

The viability and effectiveness of such systems will depend on the creek water level at the time of construction as well as the available space between where the diversion structure(s)/temporary cofferdams will be located relative to the excavation for the new culvert. In addition, any obstructions such as cobbles may need to be moved from the location of the cofferdam created from modular inflatable bladders, water dams, or large sand bags.

If water levels in the creek are high during construction, it may be necessary to install a more robust groundwater cut-off system (e.g., interlocking steel sheet piles driven to a suitable depth) to avoid excavation instability, a “boiling” or “quick” condition that would loosen/soften any of the soils, and/or cause disturbance of the foundation subgrade within the footprint of the excavation area.

The temporary cofferdams at the site should be designed and constructed in accordance with OPSS.PROV 539 (*Temporary Protection Systems)* to Performance Level 2. The design of the temporary cofferdam system should include an evaluation of tolerable lateral movement, base stability and hydraulic uplift as defined in the *Canadian Foundation Engineering Manual* (CFEM, 2006). The contractor is responsible for the design and construction of the cofferdam system. For conceptual purposes, to aid the designer in assessing the approximate construction cost of the temporary cofferdam system, the system may be designed using the parameters provided in Section 6.13.3 for Culvert Site No. 34-326/C.

6.13.5 Control of Surface Water and Groundwater - Culvert Site No. 34-326/C

Given that the culvert rehabilitation (or replacement) work will need to be carried out in the dry, control of groundwater / creek flow will be required. For the replacement option, the excavation at Culvert Site No. 34-326/C will extend through non-cohesive fill, cohesive fill, and into the clayey silt deposit. Samples of the fill and clayey silt deposits were generally characterized as moist to wet and groundwater levels (measured in open boreholes after drilling) were generally encountered within the granular fill, above the clayey silt deposit. Dewatering and surface water control will be required for excavation and construction of open footing culverts. The groundwater level must be lowered to a minimum of 1 m below the base of the excavation prior to carrying out any excavation for the culvert replacement.

The method and extent of groundwater control required will ultimately depend on the method employed to divert the creek flow during construction and/or on the type of temporary cofferdam system selected by the contractor. If temporary shoring is comprised of sheet pile cut-off walls, the requirements for groundwater control will be lessened. However, if temporary shoring is comprised of inflatable bladders, flexible tubes or sand bags (for cofferdams around the culvert inlet and outlet), the requirements for groundwater control could be more extensive. The contractor is responsible for the design and installation of all groundwater control measures giving due consideration to the type of temporary cofferdam system selected as well as the requirements for maintaining the stability/integrity of the existing culvert foundation. Unwatering, cofferdam construction and groundwater seepage control / management for the construction or rehabilitation of the culvert should be carried out in accordance with OPSS.PROV 517 (*Dewatering*) as amended by SP No. 517F01 in order to ensure the passage of the creek flow during the construction. In addition, an NSSP Dewatering Structures (i.e., cofferdams) is included in Appendix D for inclusion in the Contract Documents. .

If construction water pumping volumes are anticipated to exceed 50 m^3/day, an Environmental Activity Section Registry (EASR) will be required as per the changes to the Environmental Protection Act by the Ministry of the Environment, Conservation and Parks (MECP).

Surface water should be directed away from the work area to prevent ponding of water that could interfere with the rehabilitation and/or replacement work.

6.13.6 Control of Surface Water and Groundwater - Culvert Site Nos. 34-331/C and 34-458/C

At Culvert Site No. 34-331/C, the boreholes advanced were noted to be dry upon completion of drilling. The excavations at Culvert Site No. 34-331/C will extend through the non-cohesive and cohesive fill layers and into the clayey silt deposit. Samples of the soil at this site were generally characterized as moist and, given the relatively low permeability of the native clayey silt material and till deposit, it is likely that pumping from well filtered sumps placed at the base of the excavation will be sufficient to handle the groundwater inflows from this layer, and seepage from any water perched above this cohesive deposit, into the excavation.

At Culvert Site No. 34-458/C, the groundwater level measured in the standpipe piezometer installed in the clayey silt to silty clay deposit in Borehole 458-4 is at about Elevation 171 m, which is about 3 m to 4 m below the proposed base of the excavations, depending on the selected culvert foundation option (i.e., open footing or box culvert).

At Culvert Site No. 34-331/C, where bedrock is shallow, consideration could be given to the use of a sandbag cofferdam to reduce any infiltration of water into the excavation. At Culvert Site No. 34-458/C, consideration should be given to providing a groundwater cut-off system in conjunction with the temporary protection systems, such as sheet pilling, installed to an appropriate tip depth to cut off and reduce groundwater flow through the sides of the excavation and reduce the risk of basal instability.

If construction water pumping volumes are anticipated to exceed 50 m^3/day, an Environmental Activity Section Registry (EASR) will be required as per the changes to the Environmental Protection Act by the Ministry of the Environment, Conservation and Parks (MECP).

Surface water should be directed away from the work area to prevent ponding of water that could interfere with the rehabilitation work.

6.13.7 Obstructions During Installation of Temporary Protection Systems and Temporary Cofferdams

It is anticipated that cobble and/or boulder size materials may be encountered within the till deposit above the bedrock at Culvert Site No. 34-331/C and that cobbles may be encountered within the fill at Culvert Site No. 34-326/C. The presence of these obstructions may affect the installation of protection system elements and cofferdams. It is recommended that an NSSP be included in the Contract Documents to warn the Contractor of the possible presence of cobbles and/or boulders within the fills and overburden soils; an NSSP is provided in Appendix D.

6.13.8 Vibration Monitoring During Temporary Protection System Installation

If the temporary protection systems are installed using vibratory methods, significant vibrations are not anticipated, given the nature of the soil deposits. Residential/commercial buildings are present in the vicinity of the site, at distances of approximately 65 m, 220 m, and 40 m from the replacement Culvert Site Nos. 34-326/C, 34-458/C, and 34-331/C, respectively. A lower PPV threshold of 25 mm/s is generally considered applicable for buildings. While it is expected that vibration levels will not reach these thresholds at the structures, MTO has requested pre- and post-construction condition surveys and vibration monitoring at or near the buildings, to defend against potential damage claims associated with vibration-inducing activities at similar sites. A sample NSSP is provided in Appendix D, to address vibration monitoring condition surveys at residences located within 250 m of the construction operations at the culverts.

6.13.9 Subgrade Protection

The subgrade soils at the base level of the excavations at Culvert Site Nos. 34-326/C, 34-331/C, and 34-458/C will be susceptible to disturbance from construction traffic and/or ponded water. To limit this degradation, it is recommended that the subgrade at the culvert sites be protected within four hours of preparation, inspection, and approval of the subgrade for the box culvert or open-footing foundations. As discussed in Section 6.5.1, subgrade protection for box culverts and footings could be provided by granular bedding or a concrete working slab. This requirement can be addressed with a note on the General Arrangement drawing and/or with an NSSP, such as the sample NSSP for the working slab included in Appendix D.

7.0 CLOSURE

The Foundation Design Report was prepared by Alysha Kobylinski, E.I.T., and reviewed by Sandra McGaghran, M.Eng., P.Eng., an Associate and senior geotechnical engineer with Golder. Mr. Paul Dittrich, Ph.D., P.Eng., a Principal and MTO Foundations Designated Contact for Golder, conducted an independent quality control review of the report.

Golder Associates Ltd.

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ACK/SMM/JPD/rb

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REFERENCES

Canadian Geotechnical Society. 2006. Canadian Foundation Engineering Manual (CFEM), 4th Edition. The Canadian Geotechnical Society, BiTech Publisher Ltd., British Columbia.

Canadian Highway Bridge Design Code (CHBDC (2014)) and Commentary on CAN/CSA-S6-14. Canadian Standard Association. (CSA) Group.

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.

Concrete materials and methods of concrete construction / Test methods and standard practices for concrete (CSA A23.1-14/A23.2-14). Canadian Standard Association. (CSA) Group.

Department of Highway Ontario. Preliminary Foundation Investigation Report for Forkes Road Crossing of the Proposed Welland Canal, District No. 4 (Hamilton), W.J. 66-F-111, W.P. 242-66, dated September 12, 1967, (GEOCRES 30L14-005).

Golder Associates Limited, Ontario. 2009. Foundation Investigation and Design Report, Rehabilitation of North Embankment and Approach, Highway 140 / CNR Overpass, Port Colborne, Ontario, dated August, 2009 (GEOCRES 30L14-50).

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.

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Ladd, C.C, Foott, R., Ishihara, K., Schlosser, F., and Poulos, H.G. 1977. Stress deformation and strength characteristics. Proceedings of the 9th International Conference on Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, pp. 421494.

Mitchell, J.K. 1993. Fundamentals of Soil Behaviour. 2nd Edition, John Wiley and Sons Inc., New York.

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

Unified Facilities Criteria, U.S. Navy. 1986. NAVFAC Design Manual 7.02. Soil Mechanics, Foundation and Earth Structures. Alexandria, Virginia.

Wischmeier, W.H., and Smith, D.D. 1978. Predicting Rainfall Erosion Loses – A Guide to Conservation Planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.

ASTM International:

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

Commercial Software:

Slide (Version 8) by Rocscience Inc.

Ontario Provisional Standard Drawing:

OPSD 208.010	Benching of Earth Slopes
OPSD 810.010	Rip-Rap Treatment for Sewer and Culvert Outlets
OPSD 803.010	Backfill and Cover for Concrete Culverts
OPSD 1101.012	Precast Concrete Valve Chamber with Poured-in-Place Thrust Blocks, 1800 x 2400 mm Components
OPSD 3090.101	Foundation Frost Penetration Depths for Southern Ontario

Ontario Provincial Standard Specification:

OPSS.PROV 206	Construction Specification for Grading
OPSS.PROV 212	Construction Specification for Earth Borrow
OPSS 422	Construction Specification for Precast Reinforced Concrete Box Culverts and Box Sewers in Open Cut
OPSS.PROV 501	Construction Specifications for Compacting
OPSS.PROV 517	Construction Specification for Dewatering
OPSS.PROV 539	Construction Specification for Temporary Protection Systems
OPSS 802	Construction Specification for Topsoil
OPSS 803	Construction Specification for Sodding
OPSS.PROV 804	Construction Specification for Seed and Cover
OPSS 902	Construction Specification for Excavating and Backfilling Structures
OPSS.PROV 1002	Material Specifications for Aggregates – Concrete
OPSS.PROV 1004	Material Specification for Aggregates – Miscellaneous
OPSS.PROV 1010	Material Specification for Aggregates – Base, Subbase, Select Subgrade and Backfill Material
OPSS.PROV 1205	Material Specifications for Clay Seal
SP 105S22	Special Provision – Amendment to OPSS 501, June 2016
SP 105S09	Special Provision – Amendment to OPSS 539, November 2014
SP 109S12	Special Provision – Amendment to OPSS 902, August 2018
SP 517F01	Special Provision - Amendment to OPSS 517, July 2017

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

Highway Drainage Design Standards, January 2008

Table 1: Comparison of Alternatives for Culvert Replacement/Rehabilitation - Site Nos 34-326/C, 34-331/C and 34-458/C

Options	Advantages	Disadvantages	Relative Costs	Risks / Consequences
Box Culvert Replacement	▪ Minimizes depth of excavation, excavation support and dewatering requirements compared to open-footing option. ▪ Pre-cast box sections expected to allow faster construction than cast-in-place open footings, with shorter duration for dewatering and surface water pumping / diversion.	▪ Will require construction of a temporary cofferdam to divert Lyons Creek at Culvert Site No. 34-326/C. ▪ At Culvert Site Nos. 34-331/C and 34-458/C the flow is less and can likely be handled by a sheetpile wall or a sand bag cut-off.	▪ Less overall cost relative to open footing culvert replacement because shorter period of excavation, support and dewatering systems are required for culvert installation. ▪ Greater costs compared to rehabilitation option.	▪ May not satisfy specific fisheries requirements related to natural channel substrate, if applicable. ▪ Difficulties may be encountered with installing temporary cofferdams at Culvert Site No. 34-326/C due to the presence of cobbles.
Open Footing Culvert Replacement	▪ Would satisfy fisheries requirements related to natural channel substrate, if applicable. ▪ May be feasible to build culvert replacements on pre-cast footing sections, to accelerate construction schedule and reduce time for dewatering and surface water pumping.	▪ Excavation depths are greater than for box culvert option in order to found footings at/below depth of frost penetration, resulting in increased excavation support and dewatering requirements. ▪ Cast-in-place footings may require a longer duration for construction, including dewatering and surface water pumping, as compared with pre-cast culvert segments or footing elements.	▪ Greater overall cost relative to box culvert replacement because deeper excavations are required which will also result in additional time period for temporary support systems and dewatering system operation.	▪ Longer construction time and deeper excavations introduce greater risk to the installation of the culvert replacement. ▪ Excavations and support systems will have to penetrate deeper into stiff to very till, and/or bedrock. ▪ Groundwater levels will have to be lowered to greater depths. ▪ Difficulties may be encountered with installing temporary cofferdams at Culvert Sit No. 34-326/C due to the presence of cobbles.

Options	Advantages	Disadvantages	Relative Costs	Risks / Consequences
Rehabilitation of Existing Culvert	▪ Minimizes depth of excavation, excavation support and temporary cofferdam requirements compared to replacement options.	▪ Temporary cofferdams to divert creek still required.	▪ Lowest overall cost of the three options as deep excavations below the existing culvert are not required, which also results in shorter period of time that temporary cofferdam systems are required.	▪ Shorter construction times ▪ Difficulties may be encountered with installing temporary cofferdams at Culvert Site No. 34-326/C due to the presence of cobbles.

Table 2: Comparison of Temporary Protection System Options

Options	Advantages	Disadvantages	Relative Costs	Risks / Consequences
Soldier Pile and Lagging	▪ Better able to penetrate cobbles, boulders or other potential obstructions, and better able to penetrate denser soils where present. ▪ Relatively straightforward construction.	▪ May require pre-drilling through cobble nests, boulders or other obstructions as encountered at Culvert Site No. 34-326/C and anticipated in till at Culvert Site No. 34-331/C. ▪ May require socket penetration into strong limestone bedrock. ▪ Longer installation time compared to installation of sheet piles. ▪ Additional measures required to control groundwater / surface water seepage through lagging boards to avoid ground loss.	▪ Higher cost compared to sheet piles walls, especially if obstructions are encountered.	▪ Low risk that equipment won’t penetrate obstructions in order to achieve required depth. ▪ Risk of soil loss behind lagging if seepage not adequately / properly controlled.
Sheet Pile Wall	▪ Relatively straight forward installation provided that obstructions are not encountered. ▪ Easier to remove compared to soldier pile and lagging. ▪ Can also provide for groundwater seepage control.	▪ Cannot penetrate hard till, cobbles and boulders, or into bedrock. ▪ Not suitable at Culvert Site No. 34-331/C where bedrock is fairly shallow and just below the proposed culvert invert.	▪ Typically less expensive than soldier pile and lagging.	▪ Risk of sheet piles encountering obstructions and not achieving required depth.

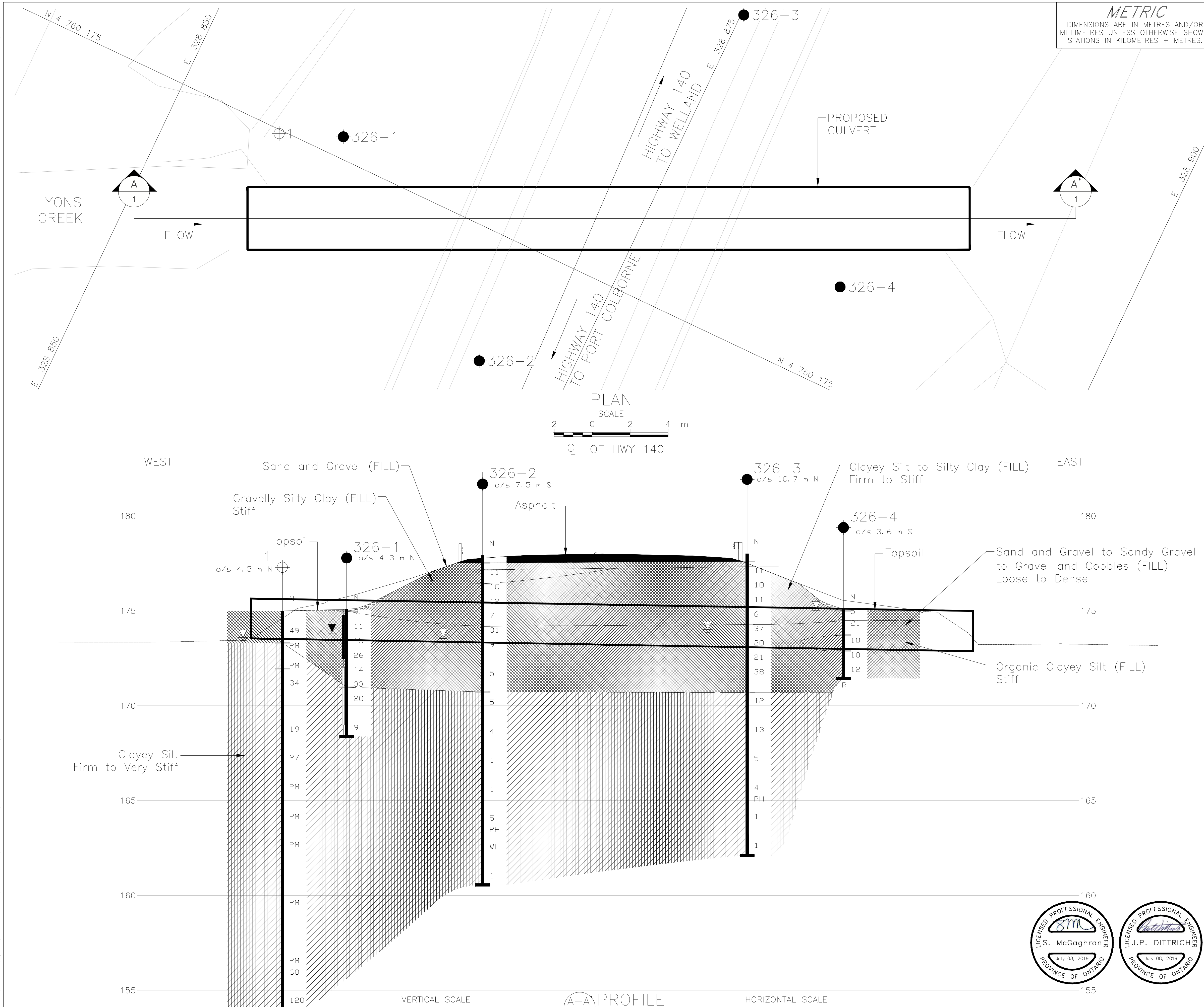
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

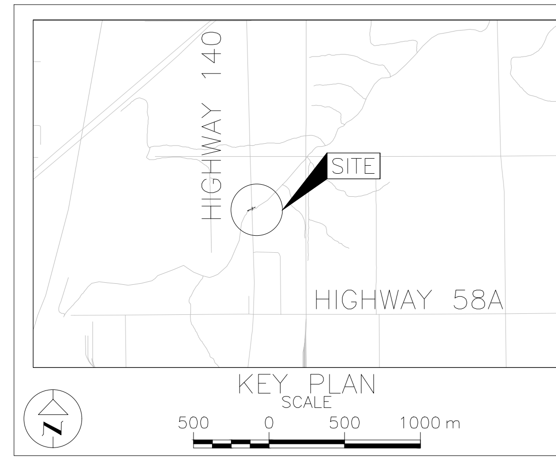
CONT No.
GWP No. 2374-15-00

HIGHWAY 140, LYONS CREEK
CULVERT REHABILITATION
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET

GOLDER





LEGEND

- ● Borehole – Current Investigation
- ⊕ Borehole – Previous Investigation (GEOCRES 30L14-030)
- Seal
- Piezometer
- N Standard Penetration Test Value
- 16 Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
- R Refusal
- WL in piezometer, measured on APR 21, 2019
- WL upon completion of drilling

BOREHOLE CO-ORDINATES (MTM NAD 83 ZONE 10)			
No.	ELEVATION	NORTHING	EASTING
1	174.8	4760174.8	328855.7
326-1	175.1	4760176.1	328858.8
326-2	177.9	4760168.5	328870.4
326-3	178.0	4760190.9	328875.1
326-4	175.1	4760180.1	328885.9

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 AIA Engineers, drawing file no. 34-326_C ACAD2010.dwg, received January 2, 2019.
General Arrangement provided in digital format by AIA Engineers, drawing file no.7010-Hwy140 Lyons-GA.dwg, received April 16, 2019.

LICENSED PROFESSIONAL ENGINEER S. McGaghran July 08, 2019 PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER J.P. DITTRICH July 08, 2019 PROVINCE OF ONTARIO

NO.	DATE	BY	REVISION

Geocres No. 30L14-62

HWY. 140	PROJECT NO. 18105193	DIST. CENTRAL
SUBM'D. ACK	CHKD. AJS	DATE: 07/08/2019	SITE: 34-326/C
DRAWN: DD	CHKD. SMM	APPD. JPD	DWG. 1

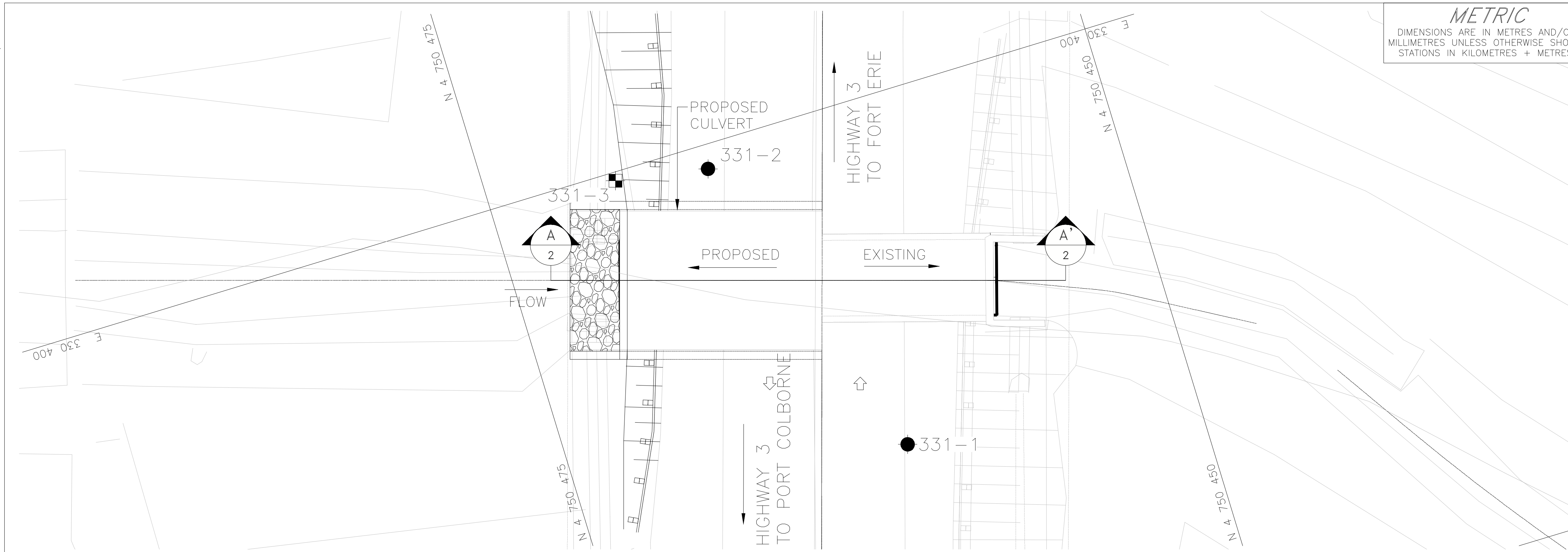
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 2374-15-00

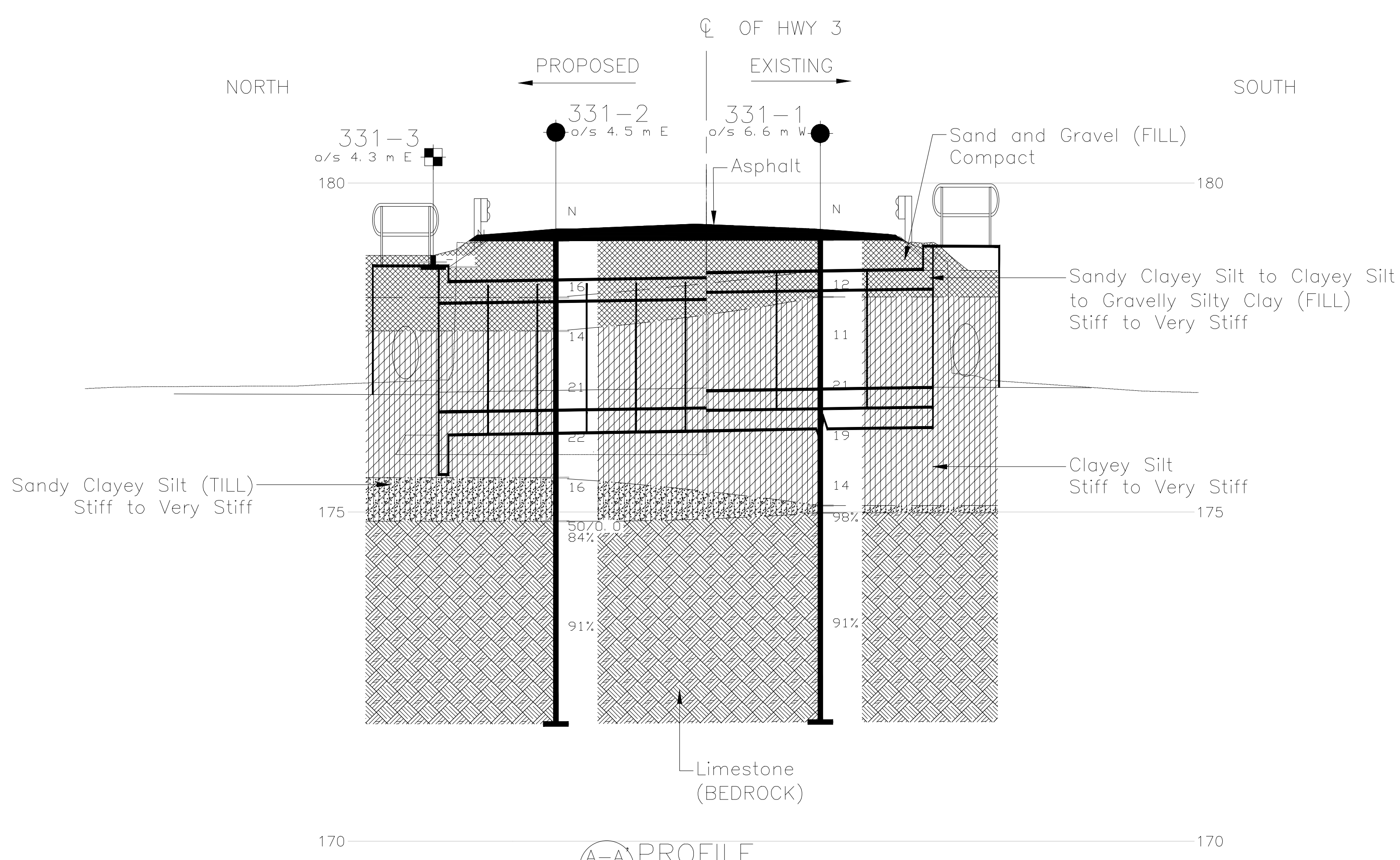
HWY 3, WEST OF WHITE ROAD
CULVERT REPLACEMENT
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET

GOLDER



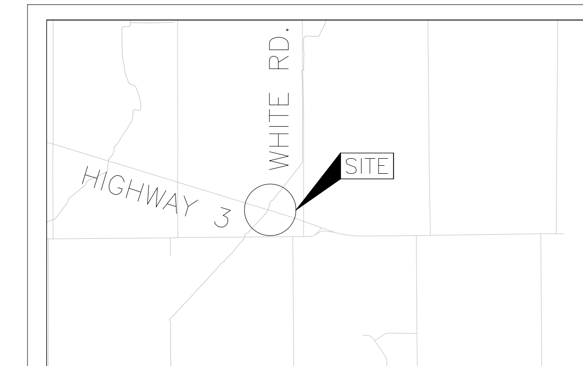
PLAN
SCALE
2 0 2 4 m



A-A 2 PROFILE

VERTICAL SCALE
1 0 1 2 m

HORIZONTAL SCALE
2 0 2 4 m



KEY PLAN
SCALE
500 0 500 1000 m

LEGEND

●	Borehole
▚	Test Pit
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
100%	Rock Quality Designation (RQD)

TEST PIT AND BOREHOLE CO-ORDINATES
(MTM NAD 83 ZONE 10)

No.	ELEVATION	NORTHING	EASTING
331-1	179.3	4750461.7	330386.1
331-2	179.3	4750466.1	330399.0
331-3	178.9	4750469.8	330399.7

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 AIA Engineers, drawing file no. 34-326_C ACAD2010.dwg, received January 2, 2019.
General Arrangement provided in digital format by AIA Engineers, drawing file no. 7010- site 34-331-Hwy3- West of White Rd-v2.dwg, received June 11, 2019.

LICENSED PROFESSIONAL ENGINEER S. McGaghran July 05, 2019 PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER J.P. DITTRICH July 05, 2019 PROVINCE OF ONTARIO

NO.	DATE	BY	REVISION

Geocres No. 30L14-62

HWY. 3	PROJECT NO. 18105193		DIST. CENTRAL
SUBM'D. AJS	CHKD. ACK	DATE: 07/05/2019	SITE: 34-331/C
DRAWN: SW	CHKD. SMM	APPD. JPD	DWG. 2

PLOT DATE: July 5, 2019
FILENAME: S:\Clients\MTO\Hwy_14D\99_PROJ\18105193\40_PROD\0003_West_of_White_Rd_Culvert\18105193-0003-BG-0001.dwg

MINISTRY OF TRANSPORTATION, ONTARIO

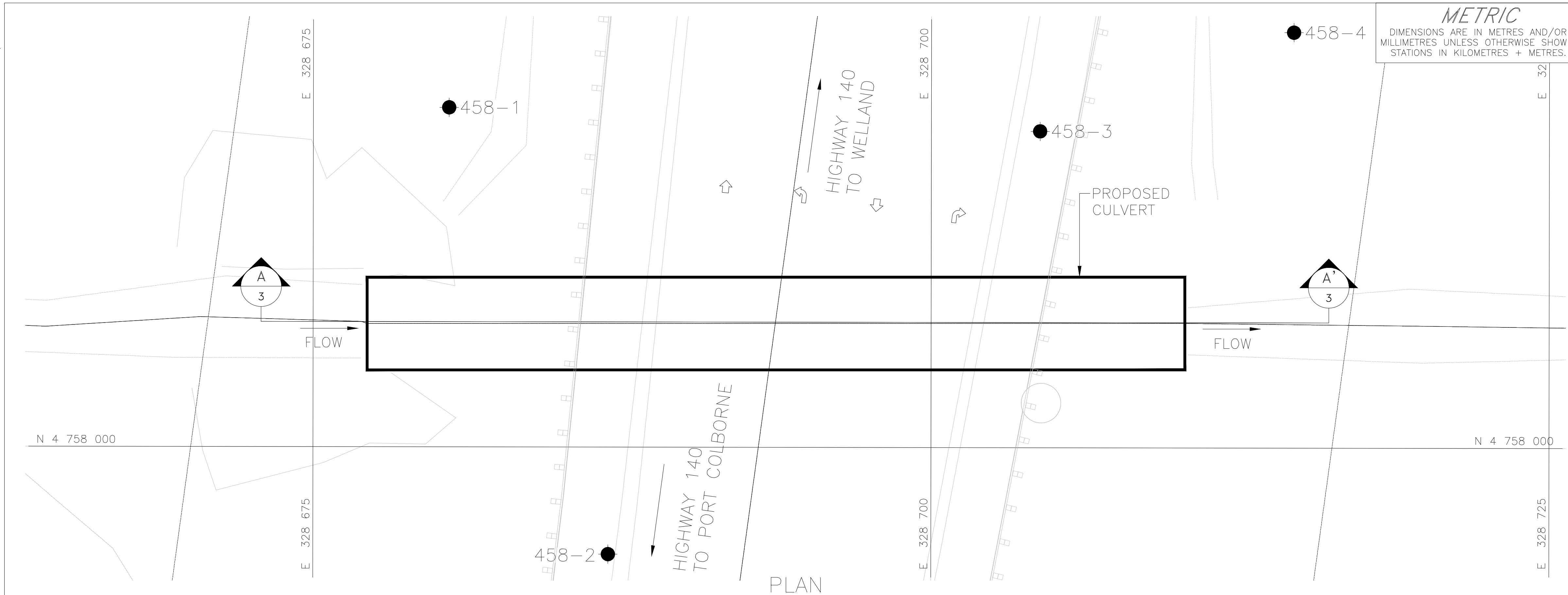
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 2374-15-00

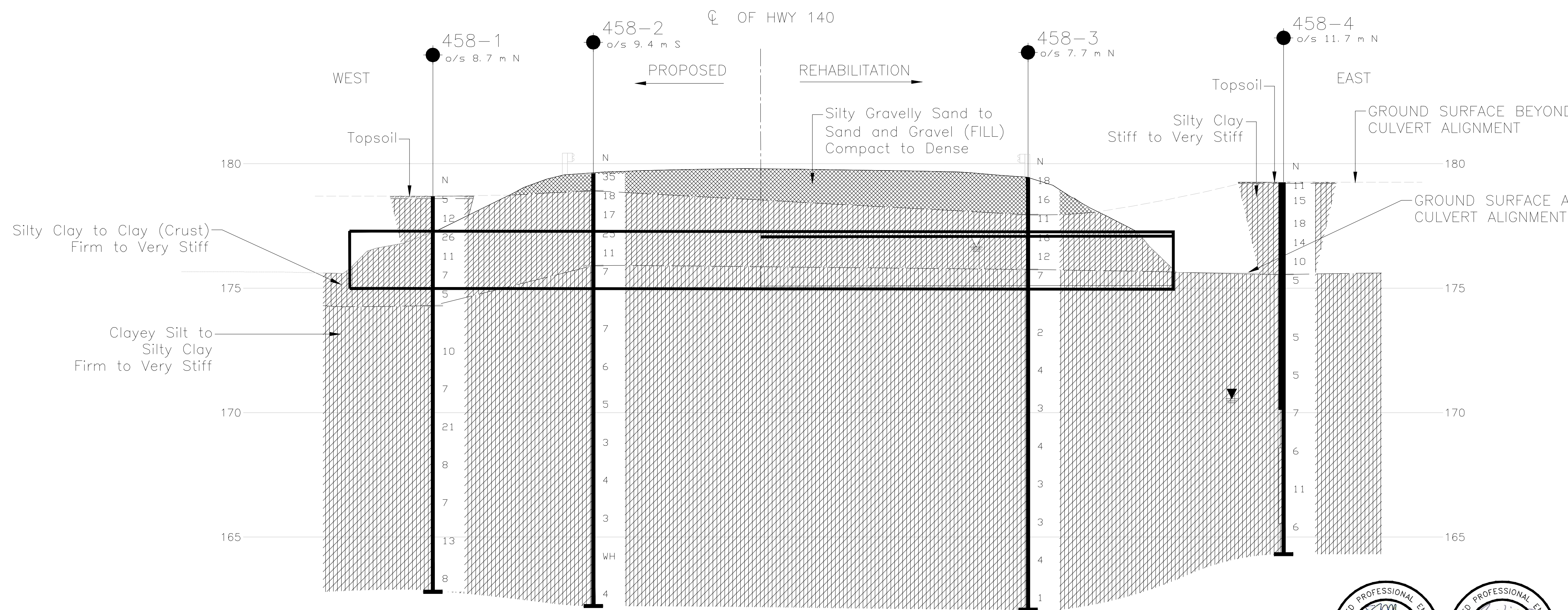
SHEET

HWY 140, NORTH OF HWY 58A
CULVERT REHABILITATION
BOREHOLE LOCATIONS AND SOIL STRATA

GOLDER



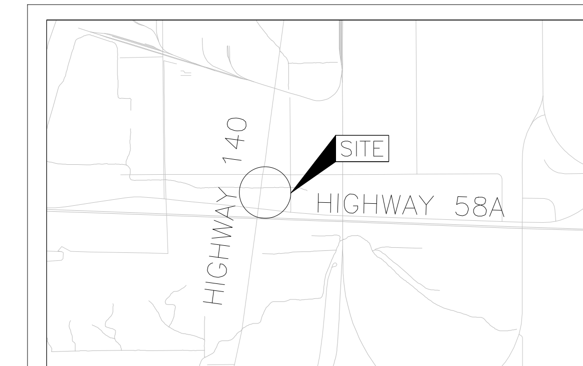
PLAN
SCALE
2 0 2 4 m



A-A 3 PROFILE

VERTICAL SCALE
2 0 2 4 m

HORIZONTAL SCALE
2 0 2 4 m



KEY PLAN
SCALE
500 0 500 1000 m

LEGEND

●	Borehole
	Seal
	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
▼	WL in piezometer, measured on APR 21, 2019
▽	WL upon completion of drilling

BOREHOLE CO-ORDINATES (MTM NAD 83 ZONE 10)

No.	ELEVATION	NORTHING	EASTING
458-1	178.7	4758013.7	328680.5
458-2	179.6	4757995.7	328686.9
458-3	179.5	4758012.8	328704.4
458-4	179.3	4758016.8	328714.7

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 AIA Engineers, drawing file no. 34-326_C ACAD2010.dwg, received January 2, 2019.
General Arrangement provided in digital format by AIA Engineers, drawing file no.7010- site 34-458- Hwy140 north of hwy 58a-GA.dwg, received June 11, 2019.

LICENSED PROFESSIONAL ENGINEER S. McGaghran July 08, 2019 PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER J.P. DITTRICH July 08, 2019 PROVINCE OF ONTARIO

NO.	DATE	BY	REVISION

Geocres No. 30L14-62

HWY. 140	PROJECT NO. 18105193	DIST. CENTRAL
SUBM'D. AJS	CHKD. ACK	DATE: 07/08/2019	SITE: 34-458/C
DRAWN: SW	CHKD. SMM	APPD. JPD	DWG. 3

PLOT DATE: July 8, 2019
FILENAME: S:\Clients\MTO\Hwy_140\99_PROJ\18105193\40_PROD\0004_North_of_HWY_58A_Culvert\18105193-0004-BC-0001.dwg

Culvert Site No. 34-326/C inlet, looking west

Culvert Site No. 34-326/C, inlet and embankment, looking south

Culvert Site No. 34-331/C outlet, looking east

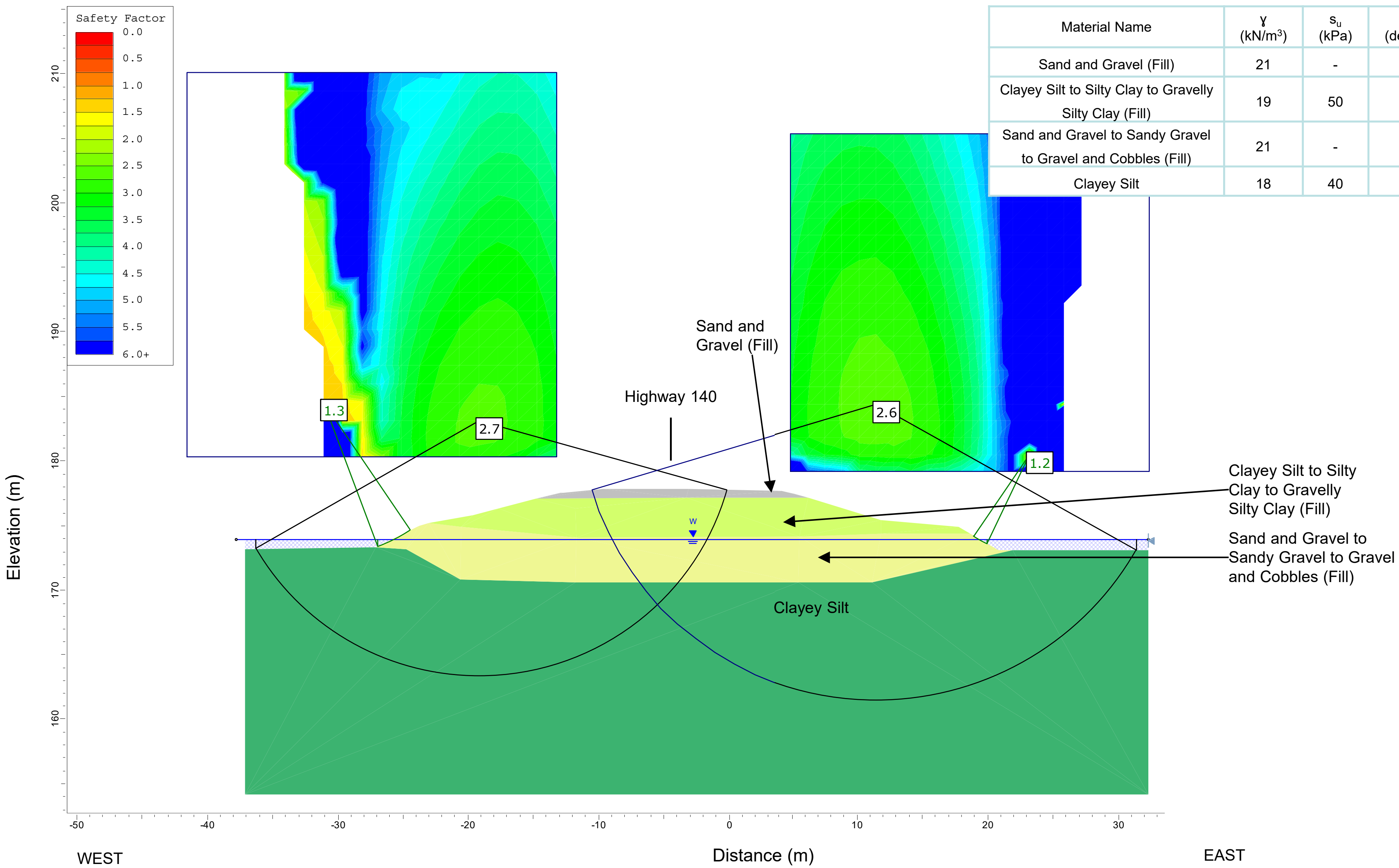
Culvert Site No. 34-458/C outlet, looking west

South of Culvert Site No. 34-458/C, looking east at the channel sideslopes east of outlet

Culvert Site No. 34-326/C, Highway 140
Global Slope Stability (Temporary/Short-Term Condition)

Figure 1A

Material Name	γ (kN/m³)	s_u (kPa)	ϕ' (degrees)
Sand and Gravel (Fill)	21	-	32
Clayey Silt to Silty Clay to Gravelly Silty Clay (Fill)	19	50	-
Sand and Gravel to Sandy Gravel to Gravel and Cobbles (Fill)	21	-	35
Clayey Silt	18	40	-



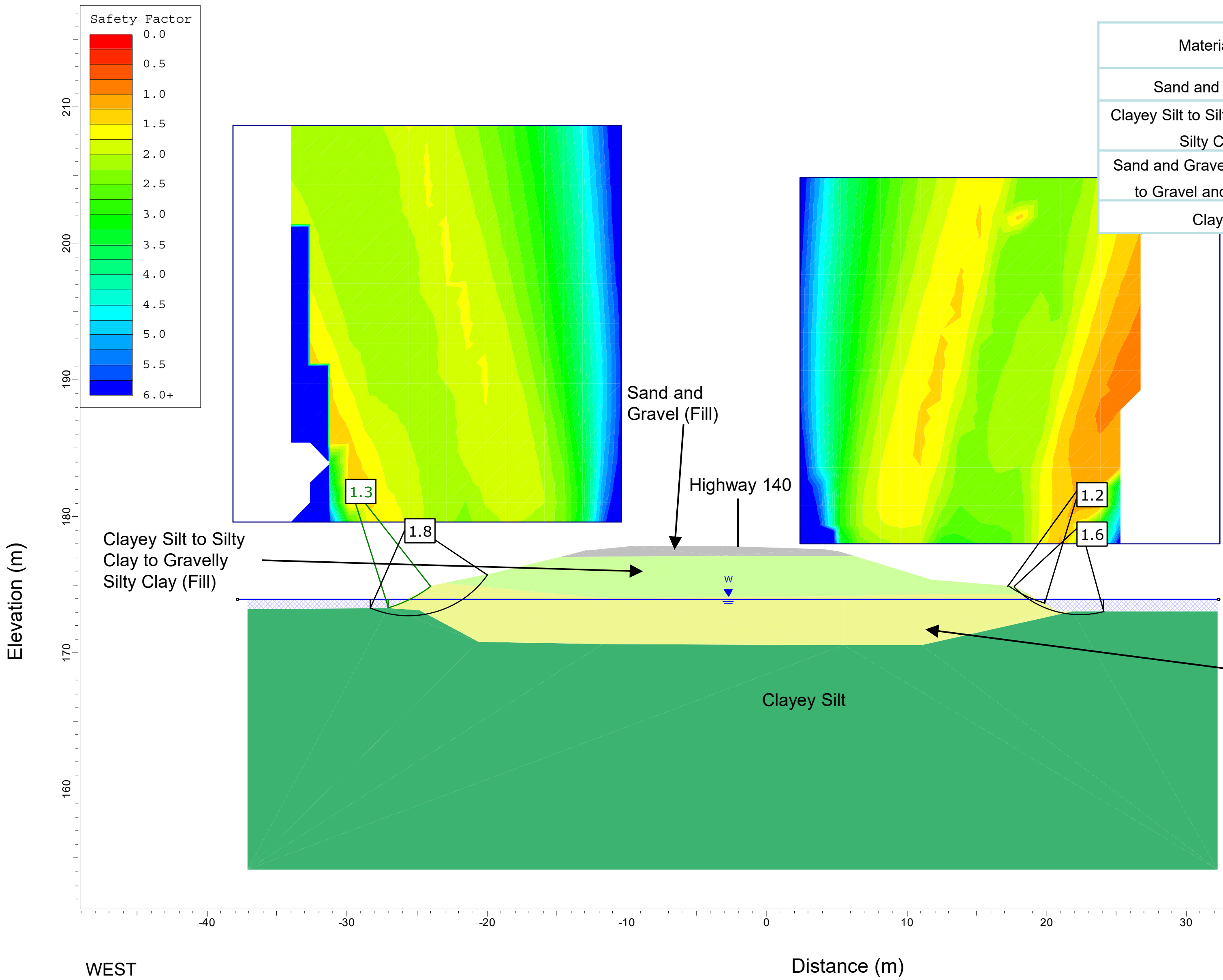
Date: July 11, 2019
Project No: 18105193

Analysis By: ACK
Reviewed By: SMM

Culvert Site No. 34-326/C, Highway 140
Global Slope Stability (Drained/Long-Term Condition)

Figure 1B

Material Name	γ (kN/m³)	s_u (kPa)	ϕ' (degrees)
Sand and Gravel (Fill)	21	-	32
Clayey Silt to Silty Clay to Gravelly Silty Clay (Fill)	19	-	23
Sand and Gravel to Sandy Gravel to Gravel and Cobbles (Fill)	21	-	35
Clayey Silt	18	-	26



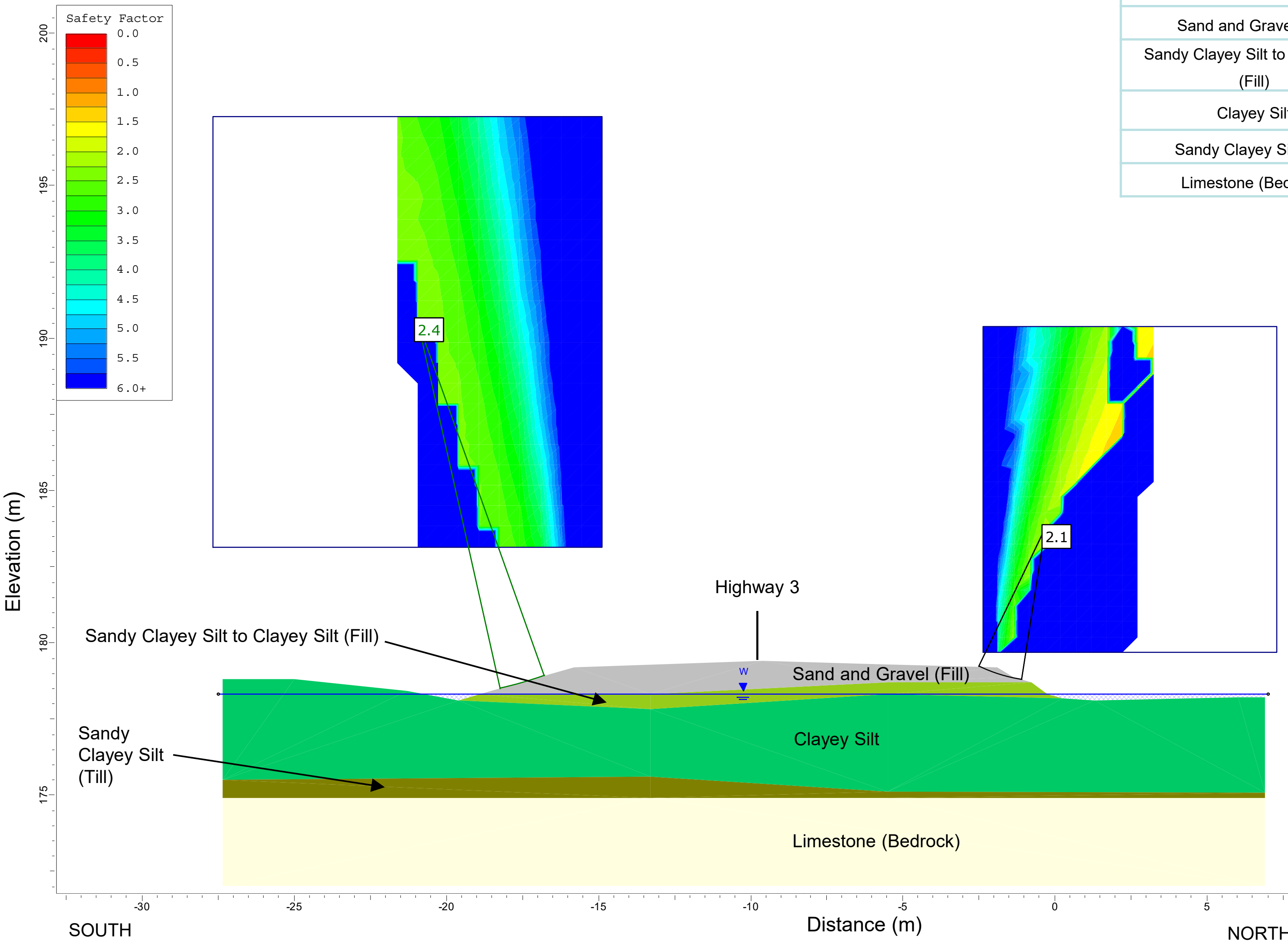
Date: July 11, 2019
Project No: 18105193

Analysis By: ACK
Reviewed By: SMM

Culvert Site No. 34-331/C, Highway 3
Global Slope Stability (Temporary/Short-Term Condition)

Figure 2A

Material Name	γ (kN/m^3)	s_u (kPa)	ϕ' (degrees)
Sand and Gravel (Fill)	21	-	35
Sandy Clayey Silt to Clayey Silt (Fill)	19	50	-
Clayey Silt	18	75	-
Sandy Clayey Silt (Till)	20	100	-
Limestone (Bedrock)	24	-	-



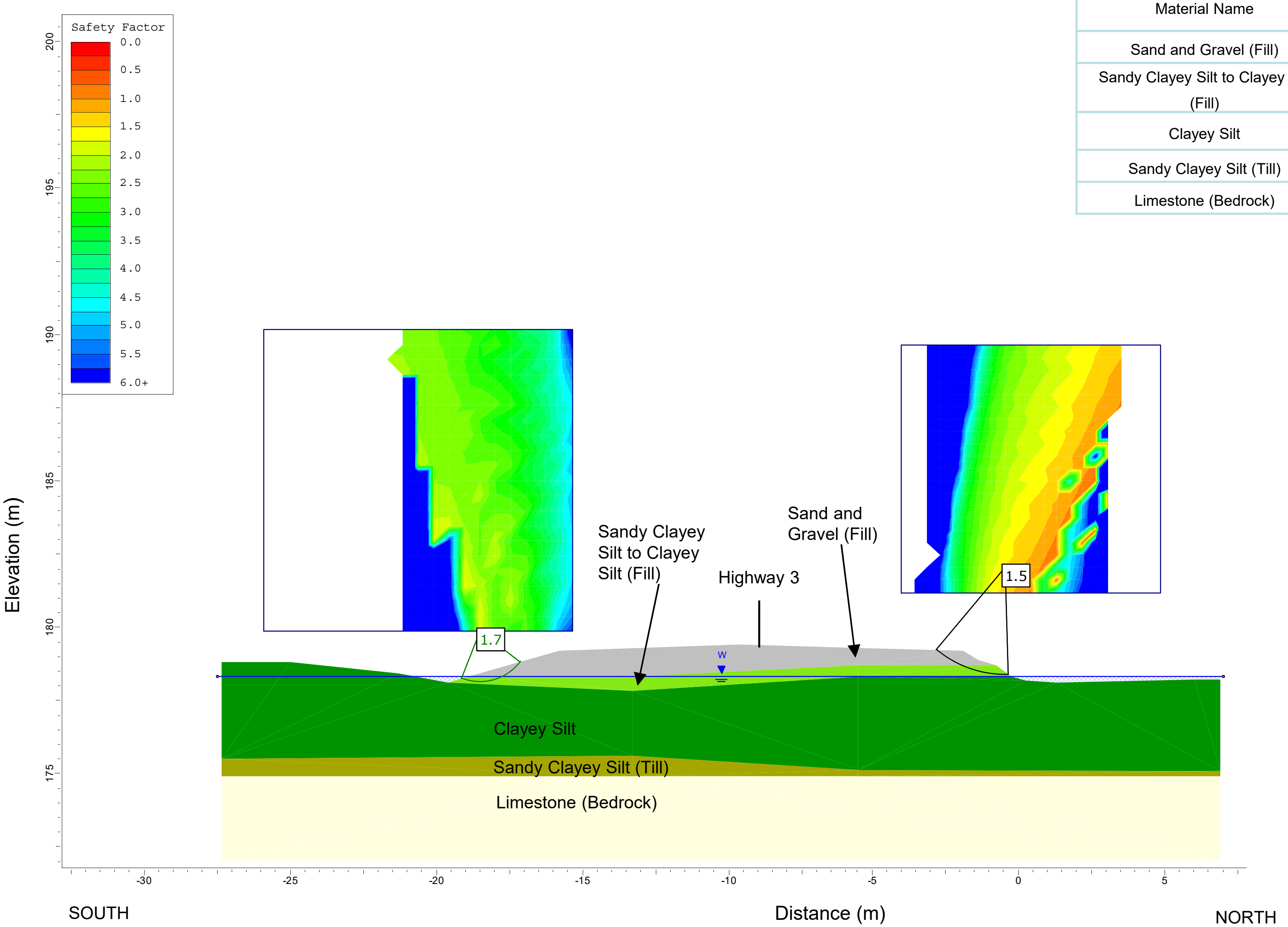
Date: July 11, 2019
Project No: 18105193

Analysis By: ACK
Reviewed By: SMM

Culvert Site No. 34-331/C, Highway 3
Global Slope Stability (Drained/Long-Term Condition)

Figure 2B

Material Name	γ (kN/m³)	s_u (kPa)	ϕ' (degrees)
Sand and Gravel (Fill)	21	-	35
Sandy Clayey Silt to Clayey Silt (Fill)	19	-	23
Clayey Silt	18	-	26
Sandy Clayey Silt (Till)	20	-	34
Limestone (Bedrock)	24	-	-



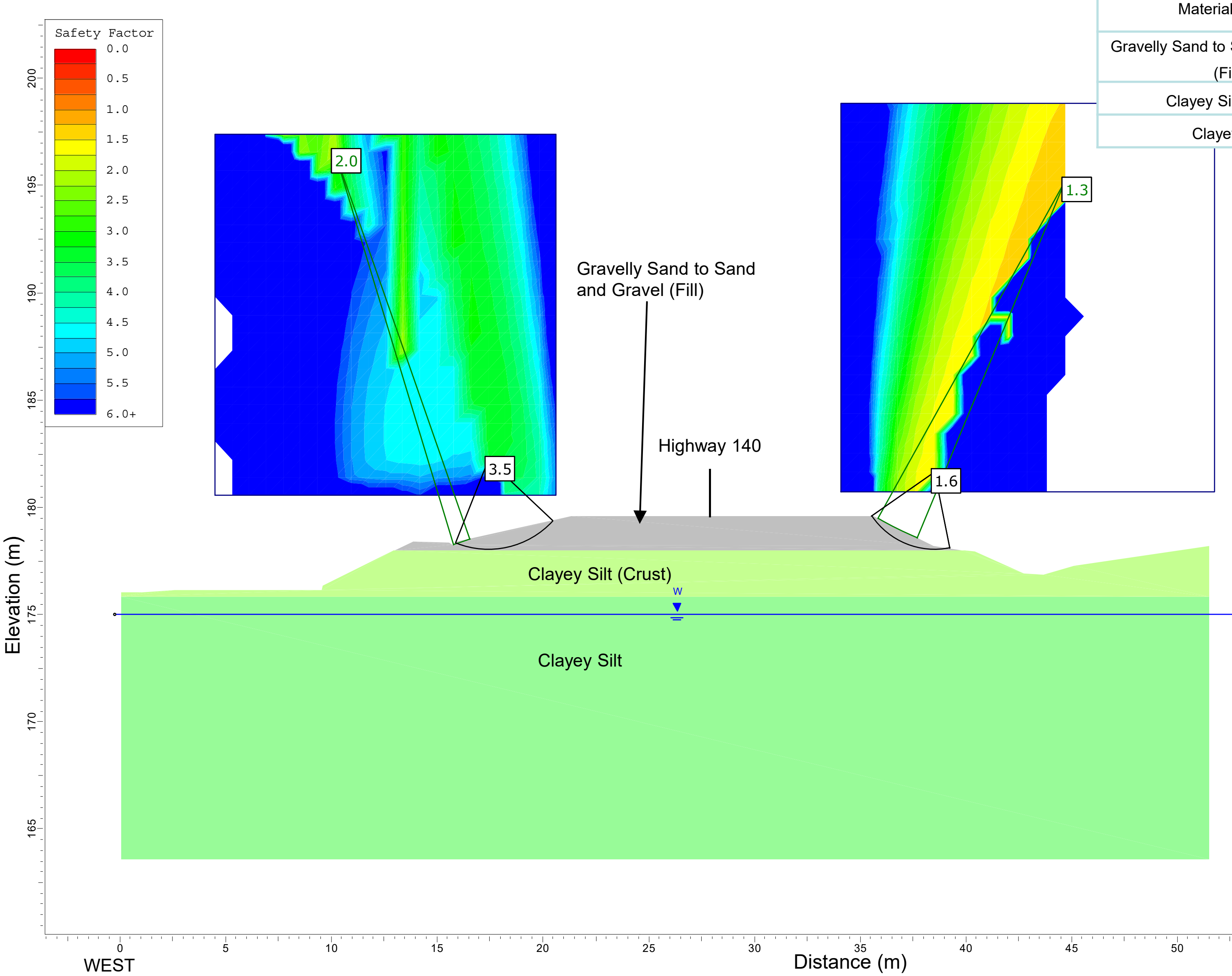
Date: July 11, 2019
Project No: 18105193

Analysis By: ACK
Reviewed By: SMM

Culvert Site No. 34-458/C, Highway 140
Global Slope Stability (Temporary/Short-Term Condition)

Figure 3A

Material Name	γ (kN/m³)	s_u (kPa)	ϕ' (degrees)
Gravelly Sand to Sand and Gravel (Fill)	20	-	33
Clayey Silt (Crust)	19	100	-
Clayey Silt	18	50	-



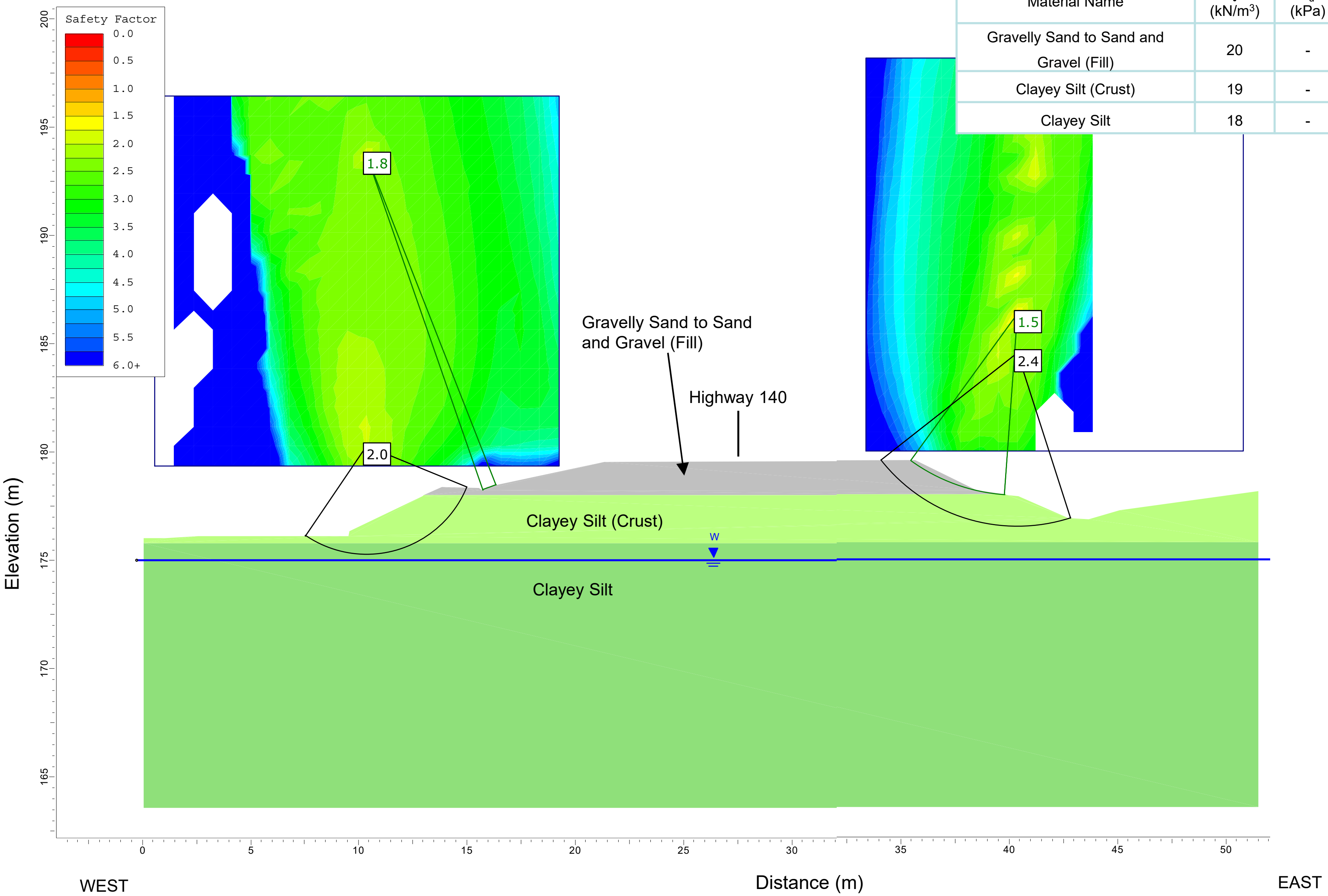
Date: July 11, 2019
Project No: 18105193

Analysis By: ACK
Reviewed By: SMM

Culvert Site No. 34-458/C, Highway 140
Global Slope Stability (Drained/Long-Term Condition)

Figure 3B

Material Name	γ (kN/m³)	s_u (kPa)	ϕ' (degrees)	c' (kPa)
Gravelly Sand to Sand and Gravel (Fill)	20	-	33	-
Clayey Silt (Crust)	19	-	24	5
Clayey Silt	18	-	26	-



Date: July 11, 2019
Project No: 18105193

Analysis By: ACK
Reviewed By: SMM

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
σ_1, σ_2, σ_3	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

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

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

(a) Index Properties (continued)

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

(b) Hydraulic Properties

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

(c) Consolidation (one-dimensional)

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

(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 (ϕ = 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

	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 90º 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		

FIELD ESTIMATION OF ROCK HARDNESS

Grade	Description	Field Identification	Approx. Range of UCS (MPa)
R0	Extremely Weak Rock	Indented by thumbnail	0.25 - 1
R1	Very Weak Rock	Material can be peeled or shaped with a knife. Crumbles under firm blows from geological hammer.	1 - 5
R2	Weak Rock	Knife cuts material but too hard to shape into triaxial specimens or material can be peeled with a knife with difficulty. Shallow (<5mm) indentations made by firm blows from pick of a geological hammer.	5 - 25
R3	Moderately Strong Rock	Cannot be peeled or scraped with a knife. Hand held specimens can be fractured with single firm blow of geological hammer.	25 - 50
R4	Strong Rock	Hand held specimen requires more than one blow of geological hammer to fracture.	50 - 100
R5	Very Strong Rock	Hand held specimen requires many blows of geological hammer to fracture.	100 - 250
R6	Extremely Strong Rock	Specimen can only be chipped under repeated hammer blows, rings when hit.	> 250

Notes:

1. Hand held specimens should have height approximately 2 times the diameter.
2. Materials having a uniaxial compressive strength of less than approximately 0.5 MPa and cohesionless materials should be classified using soil classification systems.
3. Rocks with a uniaxial compressive strength below 25 MPa (i.e. below R2) are likely to yield highly ambiguous results under point load testing.

Reference:

Brown, 1981. "Suggested Methods for Rock Characterization Testing and Monitoring", International Society for Rock Mechanics.

Hoek, E., Kaiser, P.K., Bawden, W.F., 1995. "Support of Underground Excavations in Hard Rock", Balkema, Rotterdam.

ROCK WEATHERING CLASSIFICATION

Term	Symbol	Description	Discoloration Extent	Fracture Condition	Surface Characteristics
Residual soil	W6	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	Throughout	N/A	Resembles soil
Completely weathered	W5	100% of rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	Throughout	Filled with alteration minerals	Resembles soil
Highly weathered	W4	More than 50% of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as corestones.	Throughout	Filled with alteration minerals	Friable and possibly pitted
Moderately weathered	W3	Less than 50% of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as corestones. Visible texture of the host rock still preserved. Surface planes are weathered (oxidized or carbonate filling) even when breaking the “intact rock”.	>20% of fracture spacing on both sides of fracture	Discoloured, may contain thick filling	Partial to complete discoloration, not friable except poorly cemented rocks
Slightly weathered	W2	Discoloration indicates weathering of rock material on discontinuity surfaces (usually oxidized). Less than 5% of rock mass altered.	<20% of fracture spacing on both sides of fracture	Discoloured, may contain thin filling	Partial discoloration
Fresh	W1	No visible sign of rock material weathering.	None	Closed or discoloured	Unchanged

Reference:

Brown, 1981. "Suggested Methods for Rock Characterization Testing and Monitoring", International Society for Rock Mechanics.

APPENDIX A

Record of Borehole Sheets and Geotechnical Laboratory Results for Culvert Site Nos. 34 326/C and 34-458/C

RECORD OF BOREHOLE No 326-1

SHEET 1 OF 1 **METRIC**

PROJECT 18105193

G.W.P. 2374-15-00 LOCATION N 4760176.1; E 328858.8 MTM NAD 83 ZONE 10 (LAT. 42.981016; LONG. -79.205013) ORIGINATED BY TP

DIST Central HWY 140 BOREHOLE TYPE Power Auger, 114 mm I.D. Hollow Stem Augers COMPILED BY SE

DATUM Geodetic DATE January 17, 2019 CHECKED BY AJS

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
175.1	GROUND SURFACE				175		
0.0 / 0.1	TOPSOIL (90 mm)						
	Sand and gravel, trace to some silt, trace clay (FILL) Loose to dense Brown, grey below a depth of 1.5 m Wet	1	SS	9			
		2	SS	11	174	o	53 33 12 2
		3	SS	15	173	o	
		4	SS	26			
		5	SS	14	172	o	59 32 7 2
171.0 / 4.1	CLAYEY SILT, trace to some sand, trace gravel Stiff to very stiff Brown Moist	6A / 6B	SS	33	171		
		7	SS	20	170	wP–w–wL	2 10 57 31
		8	SS	9	169		
168.4 / 6.7	END OF BOREHOLE						

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; GROUND WATER CONDITIONS; DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa: O 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 (%) 10 20 30; UNIT WEIGHT γ kN/m³.

NOTES:

1. Water level measured at a depth of about 2.0 m below ground surface (Elev. 173.1 m) upon completion of drilling.

2. Water level in piezometer:

Date	Depth (m)	Elev. (m)
3/20/2019	1.2 m	173.9 m
4/21/2019	0.9 m	174.2 m
5/29/2019	1.2 m	173.9 m

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

RECORD OF BOREHOLE No 326-2

SHEET 1 OF 2

METRIC

PROJECT 18105193			
G.W.P. 2374-15-00	LOCATION N 4760168.5; E 328870.4 MTM NAD 83 ZONE 10 (LAT. 42.980947; LONG. -79.204872)		ORIGINATED BY TP
DIST Central	HWY 140	BOREHOLE TYPE Power Auger, 114 mm I.D. Hollow Stem Augers	COMPILED BY SE
DATUM Geodetic	DATE January 16, 2019		CHECKED BY AJS

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
177.9	GROUND SURFACE
0.0	ASPHALT (400 mm)
177.5	Sand and gravel (FILL)
177.1 / 0.8	Gravelly silty clay, some sand (FILL), Stiff, Brown, Moist
176.4 / 1.5	Silty clay, trace sand (FILL), Firm to stiff, Brown, Moist
174.2 / 3.7	Sandy gravel, trace silt (FILL), Loose to dense, Grey, Wet
170.7 / 7.2	CLAYEY SILT, trace to some sand, trace gravel, Firm to stiff, Brown, Wet

Continued Next Page

SAMPLES

NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
1	AS	-		
2	SS	11		20 19 31 30
3	SS	10		
4	SS	12		0 2 46 52
5	SS	7		
6	SS	31	∇ (water level)	
7	SS	9		
8	SS	5		
9	SS	5		1 11 59 29
10	SS	4		
11	SS	1		
12	SS	1		
13	SS	5		
14	TO	PH		

ELEVATION SCALE: 177, 176, 175, 174, 173, 172, 171, 170, 169, 168, 167, 166, 165, 164

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

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

Field vane results (sensitivity): 1.7; >96; 1.7; 1.5; 2.6; 2.3

PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L; WATER CONTENT (%): 10 20 30 (liquid limit value 44 at sample 2)

UNIT WEIGHT γ kN/m³

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

RECORD OF BOREHOLE No 326-2

SHEET 2 OF 2 **METRIC**

PROJECT 18105193
G.W.P. 2374-15-00
LOCATION N 4760168.5; E 328870.4 MTM NAD 83 ZONE 10 (LAT. 42.980947; LONG. -79.204872)
ORIGINATED BY TP
DIST Central HWY 140
BOREHOLE TYPE Power Auger, 114 mm I.D. Hollow Stem Augers
COMPILED BY SE
DATUM Geodetic
DATE January 16, 2019
CHECKED BY AJS

--- CONTINUED FROM PREVIOUS PAGE ---

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	SHEAR STRENGTH kPa (FIELD VANE)
	CLAYEY SILT, trace to some sand, trace gravel Firm to stiff Brown Wet	15	SS	WH		
					162	+ (sensitivity 1.9); + (sensitivity 1.4)
		16	SS	1	161	
160.5 / 17.4	END OF BOREHOLE NOTE: 1. Water level measured at a depth of 4.3 m below ground surface (Elev. 173.6 m) upon completion of drilling.					

Column headings: SOIL PROFILE (ELEV DEPTH, DESCRIPTION, STRAT PLOT); SAMPLES (NUMBER, TYPE, "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 (%) (10, 20, 30); UNIT WEIGHT γ kN/m³; REMARKS & GRAIN SIZE DISTRIBUTION (%) (GR, SA, SI, CL)

$+^3, \times^3$: Numbers refer to Sensitivity
$\bigcirc^{3\%}$ STRAIN AT FAILURE

RECORD OF BOREHOLE No 326-3

SHEET 1 OF 2 **METRIC**

PROJECT	18105193		
G.W.P.	2374-15-00	LOCATION	N 4760190.9; E 328875.1 MTM NAD 83 ZONE 10 (LAT. 42.981149; LONG. -79.204812)
DIST	Central HWY 140	BOREHOLE TYPE	Power Auger, 114 mm I.D. Hollow Stem Augers
DATUM	Geodetic	DATE	January 15 and 16, 2019
ORIGINATED BY	KN	COMPILED BY	SE
CHECKED BY	AJS		

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
178.0	GROUND SURFACE
0.0	ASPHALT (400 mm)
177.6	Sand and gravel (FILL)
177.3 / 0.7	Silty clay, trace gravel,trace sand, trace silt pockets. trace organics at 3.1 m (FILL) Firm to stiff Brown Moist
174.3 / 3.7	Sand and gravel, trace to some silt, trace clay (FILL) Compact to dense Grey Wet
170.7 / 7.3	CLAYEY SILT trace to some gravel , trace to some sand Firm to stiff Brown Moist to wet

SAMPLES, TESTS AND REMARKS

NUMBER	TYPE	"N" VALUES	Approx. Elevation (m)	Shear Strength / Sensitivity	Remarks & Grain Size Distribution (%) GR SA SI CL
1	SS	11	177.0		
2	SS	10	176.2		
3	SS	11	175.4		1 2 56 41
4	SS	6	174.6		
5	SS	37	173.9		
6	SS	20	173.1		53 34 10 3
7	SS	21	172.4		
8	SS	38	171.6		
9	SS	12	170.1		
10	SS	13	168.6		7 10 54 29
11	SS	5	167.0		
			~166.5	Field vane, sensitivity 1.3	
			~166.1	Field vane, sensitivity 1.6	
12	SS	4	165.5		0 1 58 41
13	TO	PH	164.9		
14	SS	1	164.0		

GROUND WATER CONDITIONS: water level symbol at approx. elevation 174.1

ELEVATION SCALE: 177, 176, 175, 174, 173, 172, 171, 170, 169, 168, 167, 166, 165, 164

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: O 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 (%): 10 20 30

UNIT WEIGHT γ kN/m³

Continued Next Page

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

RECORD OF BOREHOLE No 326-3

SHEET 2 OF 2 **METRIC**

PROJECT 18105193			
G.W.P. 2374-15-00	LOCATION N 4760190.9; E 328875.1 MTM NAD 83 ZONE 10 (LAT. 42.981149; LONG. -79.204812)	ORIGINATED BY KN
DIST Central HWY 140	BOREHOLE TYPE Power Auger, 114 mm I.D. Hollow Stem Augers	COMPILED BY SE
DATUM Geodetic	DATE January 15 and 16, 2019	CHECKED BY AJS

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"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)	WATER CONTENT (%) (PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L) 10 20 30	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	--- CONTINUED FROM PREVIOUS PAGE ---										
162.1	CLAYEY SILT trace to some gravel , trace to some sand Firm to stiff Brown Moist to wet		15	SS	1				○ (~31)		
15.9	END OF BOREHOLE NOTE: 1. Water level measured at a depth of 4.0 m below ground surface (Elev. 174.0 m) upon completion of drilling on January 15, 2019										

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

GOLDER

RECORD OF BOREHOLE No 326-4

SHEET 1 OF 1 **METRIC**

PROJECT 18105193
G.W.P. 2374-15-00 LOCATION N 4760180.1; E 328885.9 MTM NAD 83 ZONE 10 (LAT. 42.981051; LONG. -79.204681) ORIGINATED BY KN
DIST Central HWY 140 BOREHOLE TYPE Portable Tripod, 150 mm O.D. casing with wash boring COMPILED BY EN
DATUM Geodetic DATE March 20 and 21, 2019 CHECKED BY AJS

ELEV DEPTH (m)	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	UNIT WEIGHT	GR	SA	SI	CL
175.1	GROUND SURFACE									
0.0	TOPSOIL (100 mm)									
0.1	Clayey silt, trace sand, trace gravel, trace to some organics (FILL) Firm Brown Moist	1	SS	5	o (~23)					
174.5 / 0.6		2	SS	21	o (~3)		65	27	6	2
173.7 / 1.4	Sandy gravel, trace to some silt, trace clay (FILL) Compact Grey Moist	3	SS	10	o (~28)	OC = 6.9%				
172.9 / 2.2	Organic clayey silt, some gravel, trace to some sand, trace to some organics (FILL) Stiff Brown Wet	4	SS	10						
	Gravel and cobbles (FILL) Compact Grey Wet	5	SS	12						
171.4 / 3.7	END OF BOREHOLE CASING REFUSAL ON COBBLES									

NOTES:

1. Borehole sampled to a depth of 1.5 m (Elev. 173.6 m) below ground surface at original Borehole 326-4 location. Casing refusal was encountered at a depth of 1.5 m (Elev. 173.6 m).

2. Additional borehole advancement attempt was made 0.3 m north of original Borehole 326-4 location. Borehole sampled from 1.5 m to 3.7 m (Elev. 171.4 m) below ground surface and samples are included in this Record of Borehole. Casing refusal was encountered at a depth of 3.7 m (Elev. 171.3 m).

3. Additional borehole advancement attempt were made 0.6 m north of the original Borehole 326-4 location. Casing refusal encountered at a depth of 3.1 m (Elev. 172.0 m) below ground surface.

4. Three additional borehole advancement attempts were made 2.6 m, 2.9 m, and 3.2 m south of the original Borehole 326-4 location. Casing refusal encountered at depths of 0.8 m and 0.9 m (Elev. 173.9 m and 174.0 m) below ground surface.

5. Water level at top of casing upon completion of drilling; however, water added during advance of casing and therefore the water level is not reflective of in-situ conditions.

$+^3, \times^3$: Numbers refer to Sensitivity O $^{3\%}$ STRAIN AT FAILURE

Foundation Design

GOLDER

RECORD OF BOREHOLE No 458-1

SHEET 1 OF 2 **METRIC**

PROJECT 18105193
G.W.P. 2374-15-00
LOCATION N 4758013.7; E 328680.5 MTM NAD 83 ZONE 10 (LAT. 42.961555; LONG. -79.207292)
ORIGINATED BY KN
DIST Central HWY 140
BOREHOLE TYPE Power Auger, 200 mm O.D. Hollow Stem Augers
COMPILED BY EN
DATUM Geodetic
DATE March 19 and 20, 2019
CHECKED BY AJS

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
178.7	GROUND SURFACE
0.0	TOPSOIL (50 mm)
0.1	SILTY CLAY to CLAY, trace sand, trace gravel Firm to very stiff Brown Moist to wet - Varved at a depth of 3.8 m to 4.4 m
174.3 / 4.4	CLAYEY SILT, trace sand Firm to very stiff Brown Moist to wet - Sandy silt pockets at a depth of 14.3 m

SAMPLES

NUMBER	TYPE	"N" VALUES	Water content / limits	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
1	SS	5		
2	SS	12	w_L = 57	0 2 21 77
3	SS	26		
4	SS	11		
5	SS	7		
6	SS	5	w_L = 50	2 1 28 69
7	SS	10		
8	SS	7		0 2 59 39
9	SS	21		
10	SS	8		
11	SS	7		0 3 56 41
12	SS	13		

Field vane results (shear strength kPa, sensitivity): >96 at approx. elev. 174.0; 1.1 at approx. elev. 170.2; 1.6 at approx. elev. 169.9; 1.1 at approx. elev. 167.1; 1.6 at approx. elev. 166.8; 1.2 at approx. elev. 165.6; >96 at approx. elev. 165.3.

Column headings: GROUND WATER CONDITIONS; ELEVATION SCALE (178 to 164); 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 (%) 10 20 30; UNIT WEIGHT γ kN/m³.

Continued Next Page

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

GOLDER

Foundation Design

RECORD OF BOREHOLE No 458-1

SHEET 2 OF 2 **METRIC**

PROJECT 18105193

G.W.P. 2374-15-00 LOCATION N 4758013.7; E 328680.5 MTM NAD 83 ZONE 10 (LAT. 42.961555; LONG. -79.207292) ORIGINATED BY KN

DIST Central HWY 140 BOREHOLE TYPE Power Auger, 200 mm O.D. Hollow Stem Augers COMPILED BY EN

DATUM Geodetic DATE March 19 and 20, 2019 CHECKED BY AJS

ELEV DEPTH	SOIL PROFILE DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	TYPE	"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)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L — WATER CONTENT (%) 10 20 30	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	--- *CONTINUED FROM PREVIOUS PAGE* ---										
	CLAYEY SILT, trace sand Firm to very stiff Brown Moist to wet		13	SS	8		163		○ (~31)		
162.8 15.9	END OF BOREHOLE NOTE: 1. Borehole open and dry upon completion of soil drilling.										

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

GOLDER

Foundation Design

RECORD OF BOREHOLE No 458-2

SHEET 1 OF 2

METRIC

PROJECT 18105193

G.W.P. 2374-15-00

LOCATION N 4757995.7; E 328686.9 MTM NAD 83 ZONE 10 (LAT. 42.961392; LONG. -79.207213)

ORIGINATED BY KN

DIST Central HWY 140

BOREHOLE TYPE Power Auger, 70 mm I.D. Hollow Stem Augers

COMPILED BY SE

DATUM Geodetic

DATE January 10, 2019

CHECKED BY AJS

SOIL PROFILE

ELEV / DEPTH (m)	DESCRIPTION
179.6	GROUND SURFACE
0.0	Silty gravelly sand, trace clay (FILL) Dense Brown Moist
178.9 / 0.7	SILTY CLAY to CLAY, trace sand Stiff to very stiff Brown Moist
175.9 / 3.7	CLAYEY SILT to SILTY CLAY trace sand, trace gravel Stiff to very stiff Brown, mottled grey Moist to wet at a depth below 13.7 m

SAMPLES

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR	SA	SI	CL
1	SS	35	29	47	21	3
2	SS	18				
3	SS	17				
4	SS	25	0	2	43	55
5	SS	11				
6	SS	7				
7	SS	7				
8	SS	6	0	2	62	36
9	SS	5				
10	SS	3				
11	SS	4				
12	SS	3	0	1	51	48

Elevation scale: 179, 178, 177, 176, 175, 174, 173, 172, 171, 170, 169, 168, 167, 166, 165

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20, 40, 60, 80, 100

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

Field vane values plotted: >96 (about elev. 175); 1.8, >96 (about elev. 172.5); 1.8, 1.7 (about elev. 171); 1.9, >96 (about elev. 166.5)

PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L; WATER CONTENT (%): 10, 20, 30 (liquid limit 47 at Sample 4)

UNIT WEIGHT γ kN/m³

Continued Next Page

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

GOLDER

RECORD OF BOREHOLE No 458-2

METRIC

PROJECT 18105193			
G.W.P. 2374-15-00	LOCATION N 4757995.7; E 328686.9 MTM NAD 83 ZONE 10 (LAT. 42.961392; LONG. -79.207213)	ORIGINATED BY KN
DIST Central HWY 140	BOREHOLE TYPE Power Auger, 70 mm I.D. Hollow Stem Augers	COMPILED BY SE
DATUM Geodetic	DATE January 10, 2019	CHECKED BY AJS

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"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 (%) 10 20 30	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	--- CONTINUED FROM PREVIOUS PAGE ---										
	CLAYEY SILT to SILTY CLAY trace sand, trace gravel Stiff to very stiff Brown, mottled grey Moist to wet at a depth below 13.7 m		13	SS	WH		164				
								+ 2.5 (field vane, ~60 kPa); + 2.1 (field vane, ~78 kPa)			
							163				
162.2			14	SS	4				○ (~30%)		
17.4	END OF BOREHOLE NOTE: 1. Borehole dry and open to a depth of 14.6 m below ground surface (Elev. 165.0 m) upon completion of drilling and removal of augers.										

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

Foundation Design

RECORD OF BOREHOLE No 458-3

SHEET 1 OF 2 **METRIC**

PROJECT	18105193		
G.W.P.	2374-15-00	LOCATION	N 4758012.8; E 328704.4 MTM NAD 83 ZONE 10 (LAT. 42.961546; LONG. -79.206999)
ORIGINATED BY	KN		
DIST	Central	HWY	140
BOREHOLE TYPE	Power Auger, 70 mm I.D. Hollow Stem Augers	COMPILED BY	SE
DATUM	Geodetic	DATE	January 8 and 9, 2019
CHECKED BY	AJS		

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
179.5	GROUND SURFACE
0.0	Sand and gravel, some silt, trace clay (FILL) Compact Grey Moist - Clayey silt,some sand, trace to some gravel from 0.8 m to 0.9 m
178.0 / 1.5	SILTY CLAY to CLAY, trace rootlets at a depth of 7.9 m, trace sand Stiff to very stiff Brown, mottled grey Moist to wet
175.8 / 3.7	CLAYEY SILT, trace sand, rootlets at a depth of 7.9 m Stiff Brown Moist to wet

SAMPLES

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR / SA / SI / CL
1	SS	18	
2	SS	16	
3	SS	11	0 / 0 / 30 / 70
4	SS	16	
5	SS	12	0 / 1 / 49 / 50
6	SS	7	
7	SS	2	
8	SS	4	
9	SS	3	
10	SS	4	
11	SS	3	
12	SS	3	0 / 1 / 71 / 28

Ground water level symbol (▽) at approximately elev. 176.8.

Elevation scale: 179, 178, 177, 176, 175, 174, 173, 172, 171, 170, 169, 168, 167, 166, 165

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20, 40, 60, 80, 100

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

Field vane sensitivities (plotted): 1.9, 1.8 (≈elev. 174.5–174.8); 3.2, 2.0 (≈elev. 172.2–172.5); 1.9, 1.7 (≈elev. 170.6–170.9); 1.8, 1.6 (≈elev. 169.1–169.4)

PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L; WATER CONTENT (%): 10, 20, 30

Liquid limit values shown: 58 (sample 3), 47 (sample 5)

UNIT WEIGHT γ kN/m³

Continued Next Page

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

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RECORD OF BOREHOLE No 458-3

SHEET 2 OF 2 — **METRIC**

PROJECT 18105193

G.W.P. 2374-15-00

LOCATION N 4758012.8; E 328704.4 MTM NAD 83 ZONE 10 (LAT. 42.961546; LONG. -79.206999)

ORIGINATED BY KN

DIST Central HWY 140

BOREHOLE TYPE Power Auger, 70 mm I.D. Hollow Stem Augers

COMPILED BY SE

DATUM Geodetic

DATE January 8 and 9, 2019

CHECKED BY AJS

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"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)	WATER CONTENT (%) (W_P — W — W_L; 10 20 30)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	--- CONTINUED FROM PREVIOUS PAGE ---										
	CLAYEY SILT, trace sand, rootlets at a depth of 7.9 m Stiff Brown Moist to wet	hatched	13	SS	4		164				
							163	+ 2.3; + 1.8			
162.1			14	SS	1				○		
17.4	END OF BOREHOLE NOTE: 1. Water level at a depth of 2.8 m below ground surface (Elev. 176.7 m) on the morning of January 9, 2019. 2. Borehole dry and open to a depth of 5.5 m below ground surface (Elev. 174.0) upon completion of drilling and removal of augers.										

$+^3, \times^3$: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

GOLDER

RECORD OF BOREHOLE No 458-4

SHEET 1 OF 2 **METRIC**

PROJECT 18105193

G.W.P. 2374-15-00

DIST Central HWY 140

DATUM Geodetic

LOCATION N 4758016.8; E 328714.7 MTM NAD 83 ZONE 10 (LAT. 42.961582; LONG. -79.206873)

BOREHOLE TYPE Power Auger, 200 mm O.D. Hollow Stem Augers

DATE March 18 and 19, 2019

ORIGINATED BY KN

COMPILED BY EN

CHECKED BY AJS

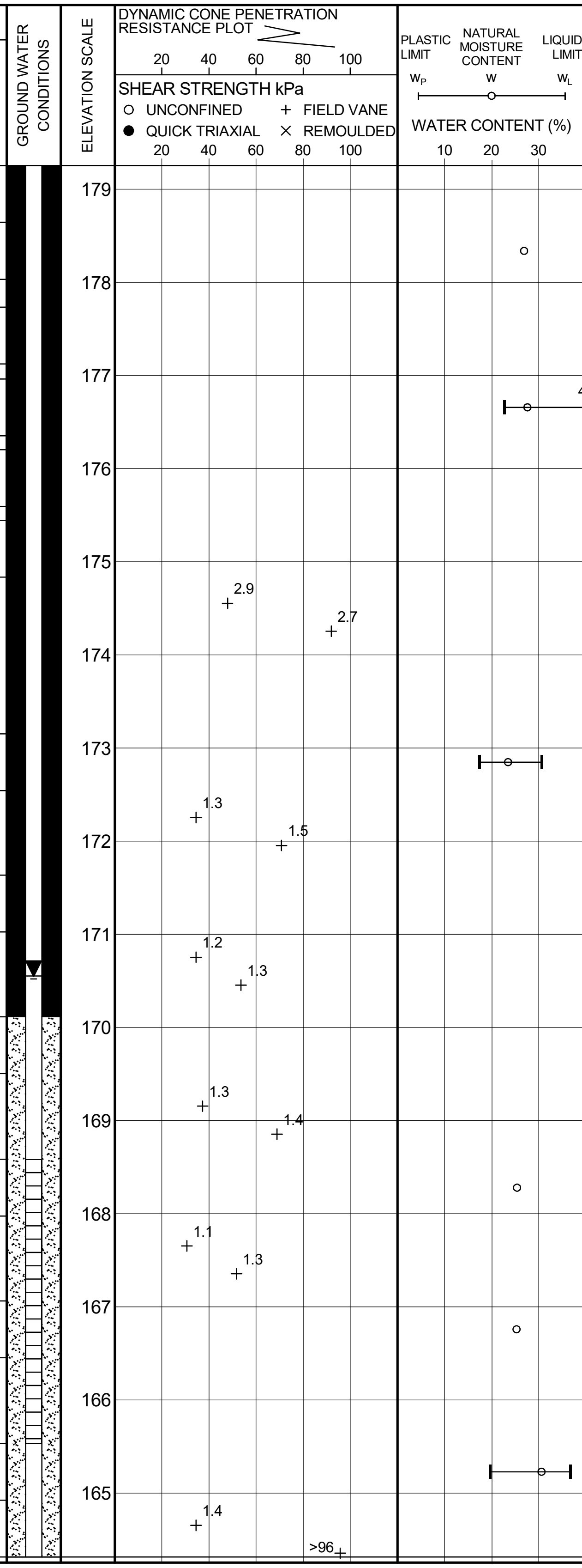
SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
179.3	GROUND SURFACE
0.0 / 179.2 / 0.1	TOPSOIL (50 mm)
	SILTY CLAY, trace sand, sand pockets Stiff to very stiff Brown Moist to wet
175.6 / 3.7	CLAYEY SILT to SILTY CLAY, trace sand Firm to very stiff Brown to grey-brown to red-brown below a depth of 12.2 m Moist to Wet
164.4	

SAMPLES

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR	SA	SI	CL
1	SS	11				
2	SS	15				
3	SS	18				
4	SS	14	0	2	34	64
5	SS	10				
6	SS	5				
7	SS	5	0	2	58	40
8	SS	5				
9	SS	7				
10	SS	6				
11	SS	11				
12	SS	6	0	1	47	52

STRAT PLOT | GROUND WATER CONDITIONS | ELEVATION SCALE | UNIT WEIGHT γ kN/m³



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

RECORD OF BOREHOLE No 458-4

SHEET 2 OF 2 **METRIC**

PROJECT 18105193

G.W.P. 2374-15-00 LOCATION N 4758016.8; E 328714.7 MTM NAD 83 ZONE 10 (LAT. 42.961582; LONG. -79.206873) ORIGINATED BY KN

DIST Central HWY 140 BOREHOLE TYPE Power Auger, 200 mm O.D. Hollow Stem Augers COMPILED BY EN

DATUM Geodetic DATE March 18 and 19, 2019 CHECKED BY AJS

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 (%) (10 20 30)	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 ---										
14.9	END OF BOREHOLE										

NOTES:

1. Water level measured at a depth of about 13.7 m below ground surface (Elev. 165.6 m) upon completion of drilling.

2. Water level in piezometer:

Date	Depth (m)	Elev. (m)
3/20/2019	12.1 m	167.2 m
4/21/2019	8.7 m	170.6 m
5/29/2019	8.7 m	170.6 m

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$+^3, \times^3$: Numbers refer to Sensitivity ○$^{3\%}$ STRAIN AT FAILURE

DEPARTMENT OF HIGHWAYS - ONTARIO
MATERIALS & TESTING OFFICE

RECORD OF BOREHOLE No. 1

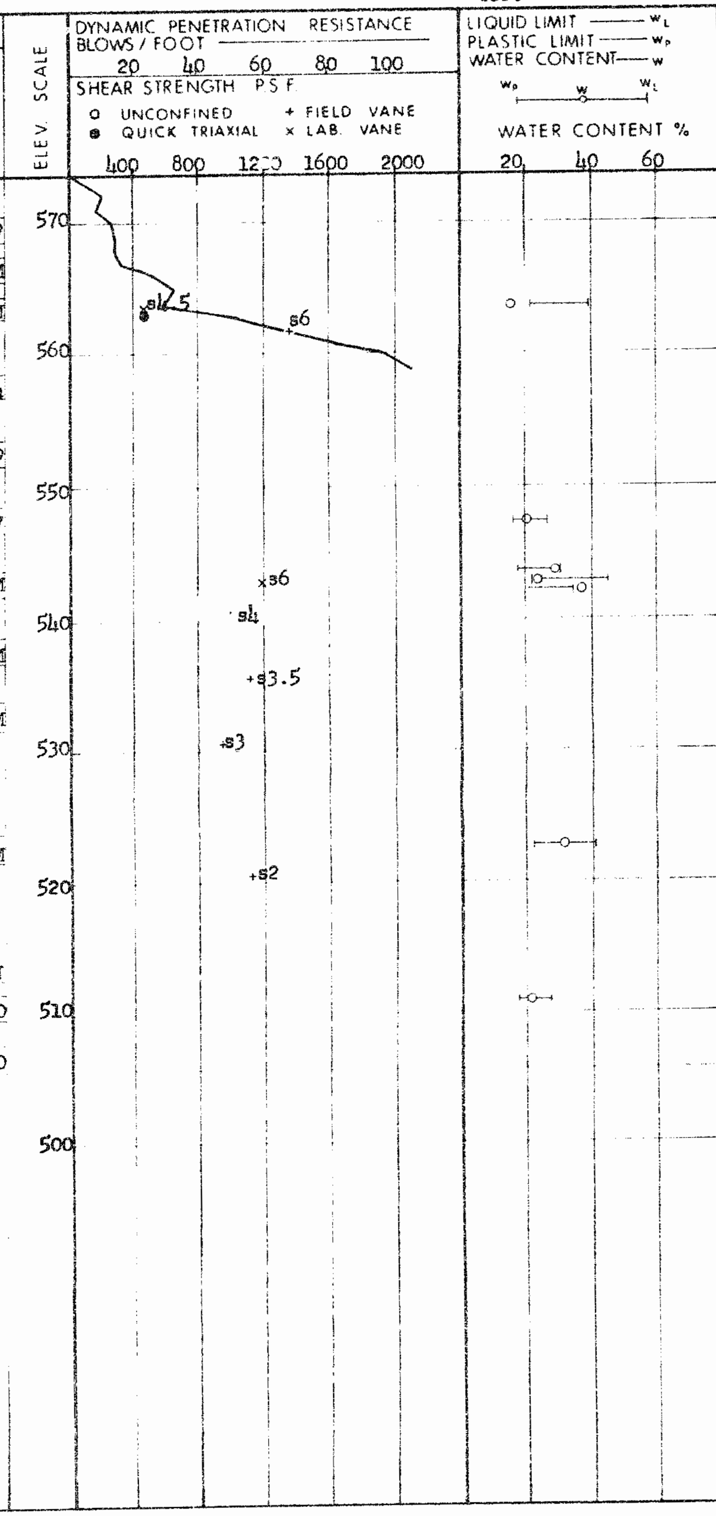
FOUNDATION SECTION

JOB 69-F-64 LOCATION 342+23 51' Lt. ORIGINATED BY BTD

W.P. 60-68-04 BORING DATE December 4, 5 and 6, 1969 COMPILED BY BTD

DATUM Geodetic BOREHOLE TYPE Washboring -NX Casing, Dynamic Cone Penetration Test CHECKED BY

ELEV. DEPTH	DESCRIPTION	NUMBER	TYPE	BLOWS / FOOT	BULK DENSITY γ P.C.F.	REMARKS
573.5	Ground Level					
0.0	Clayey Silt, trace of sand and gravel, occ. rock fragments (FILL) (Grey Brown) HARD	1	SS	49		▼ 569.5 W.L. in Open BH Dec. 6/69
568.0 / 5.5	Clayey silt, with related org. matt, wood chips etc. FIRM	2	TW	PM		
563.5 / 10.0	Silty Clay to Clayey Silt trace of sand and gravel (occasional partings and seam of silt up to 1/4" thick) (Mottled Brown to Reddish Brown) Hard to Firm	3	TW	PM	117	
		4	SS	34		
		5	SS	19		
		6	SS	27	C / 116	
		7	TW	PM		
		8	TW	PM		
		9	TW	PM		
		10	TW	PM	115	
513.5 / 60.0	(Layers of silt up to 3" thick) Hard	11	TW	PM		
		12	SS	60		
		13	SS	120		
505.5 / 68.0	End of Borehole					

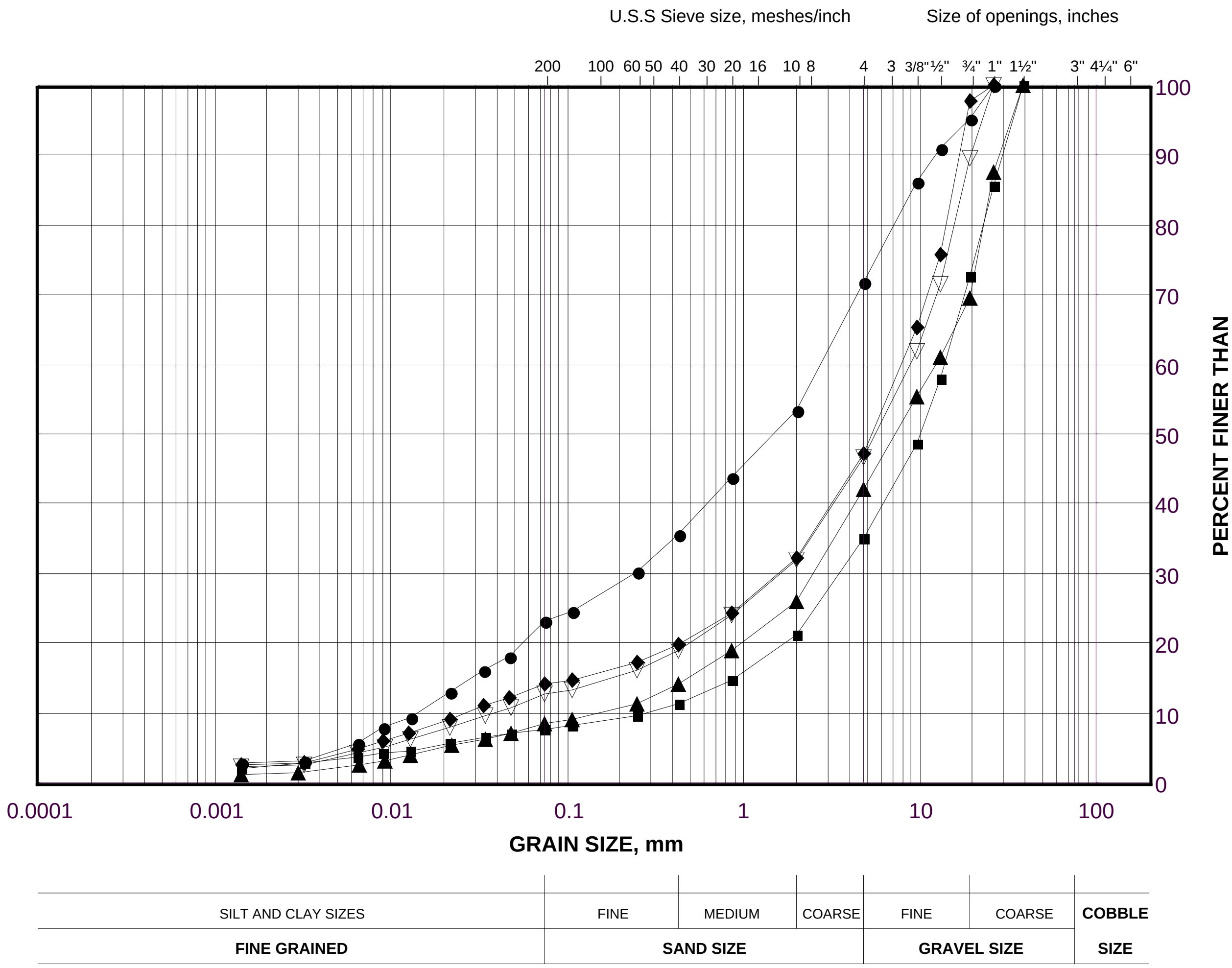


20 / 15 -◇- 5 / 10 % STRAIN AT FAILURE

GRAIN SIZE DISTRIBUTION

Silty Gravelly Sand to Sandy Gravel (FILL)

FIGURE A-1



LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	458-2	1	179.3
■	326-4	2	174.2
◆	326-1	2	174.0
▲	326-1	5	171.7
▽	326-3	6	173.1

Project Number: 18105193

Checked By: SMM

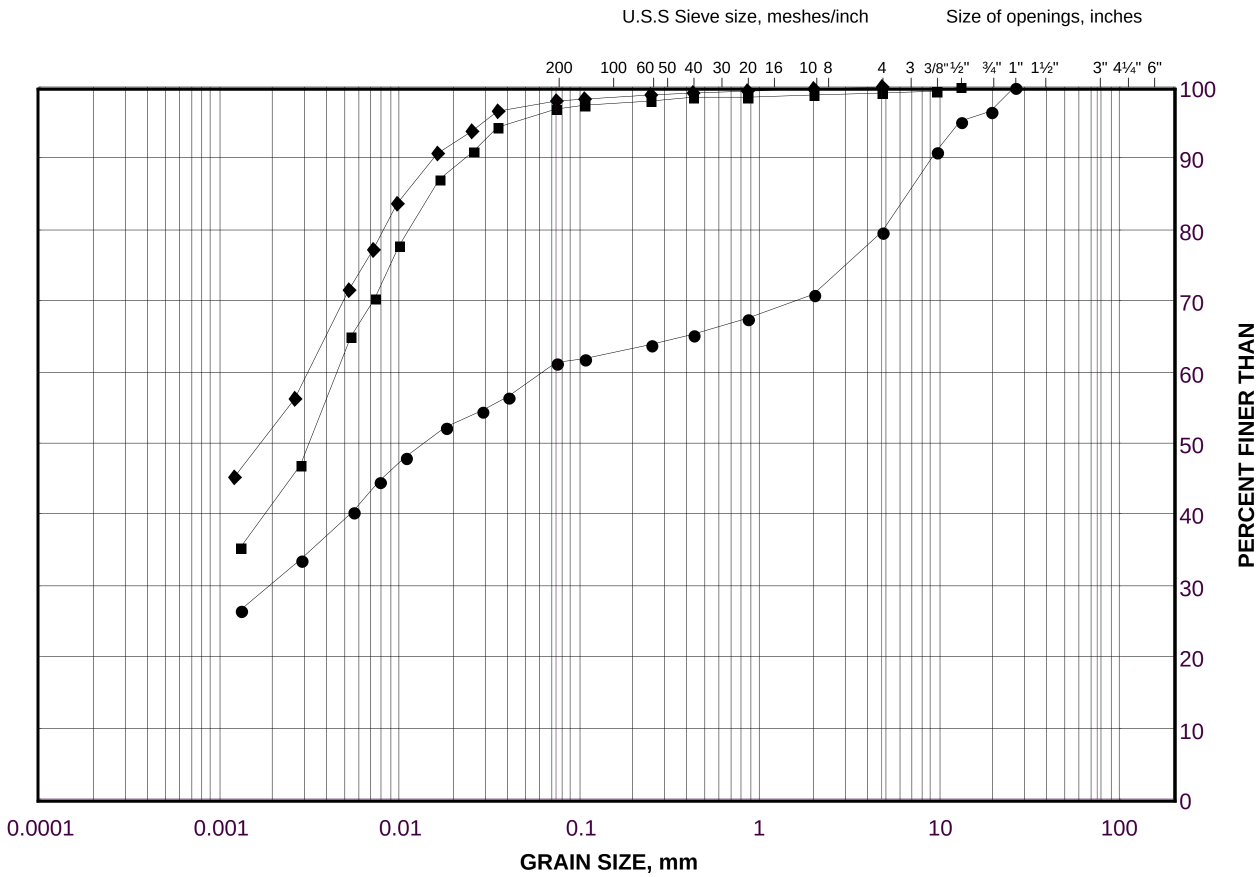
Golder Associates

Date: 08-May-19

GRAIN SIZE DISTRIBUTION

Gravelly Silty Clay to Silty Clay (FILL)

FIGURE A-2



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

LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	326-2	2	176.8
■	326-3	3	175.5
◆	326-2	4	175.3

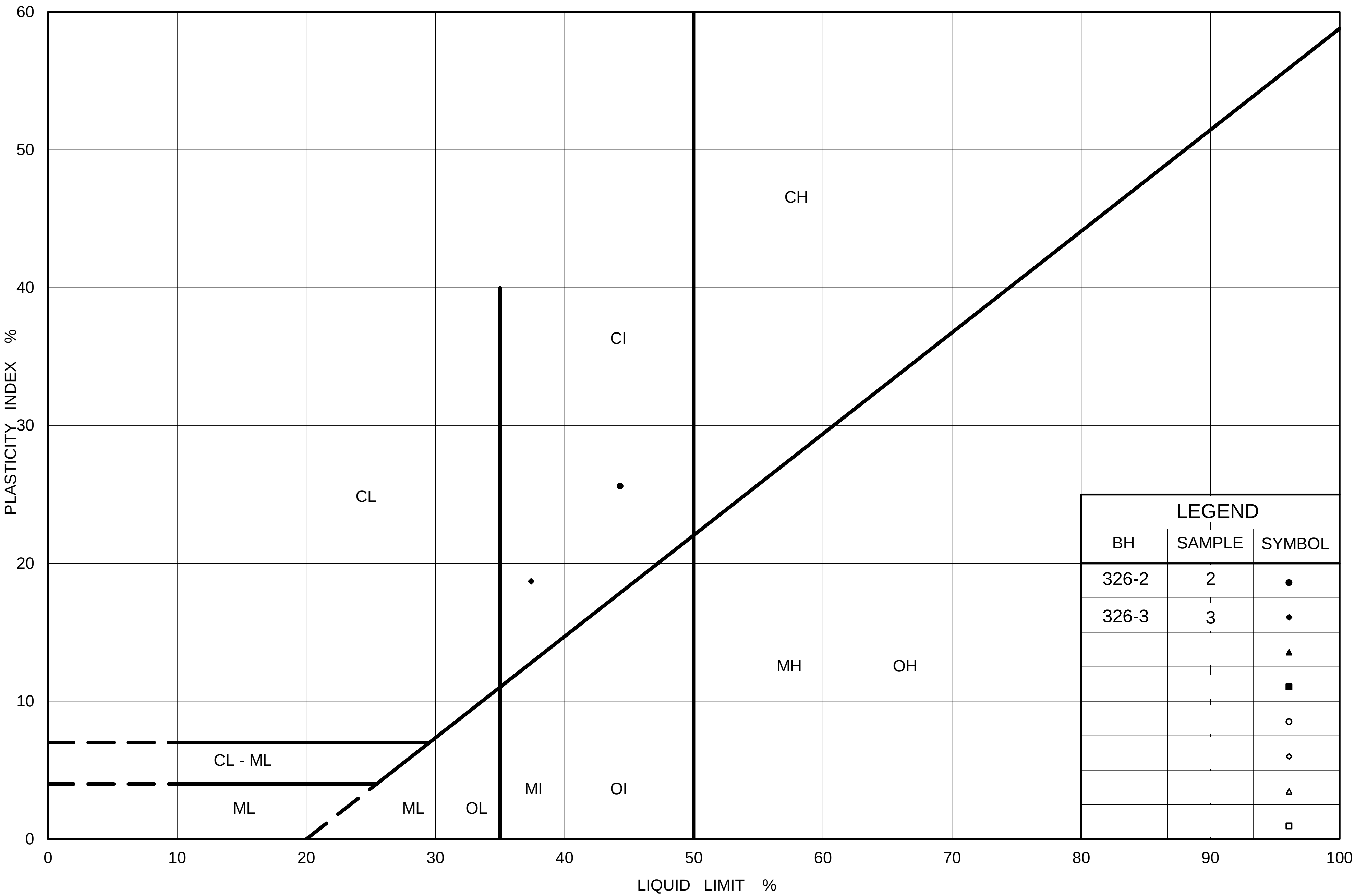
Project Number: 18105193

Checked By: SMM

Golder Associates

Date: 02-May-19

Oct 75, FF-S-21



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Ontario

PLASTICITY CHART
Gravelly Silty Clay to Silty Clay (FILL)

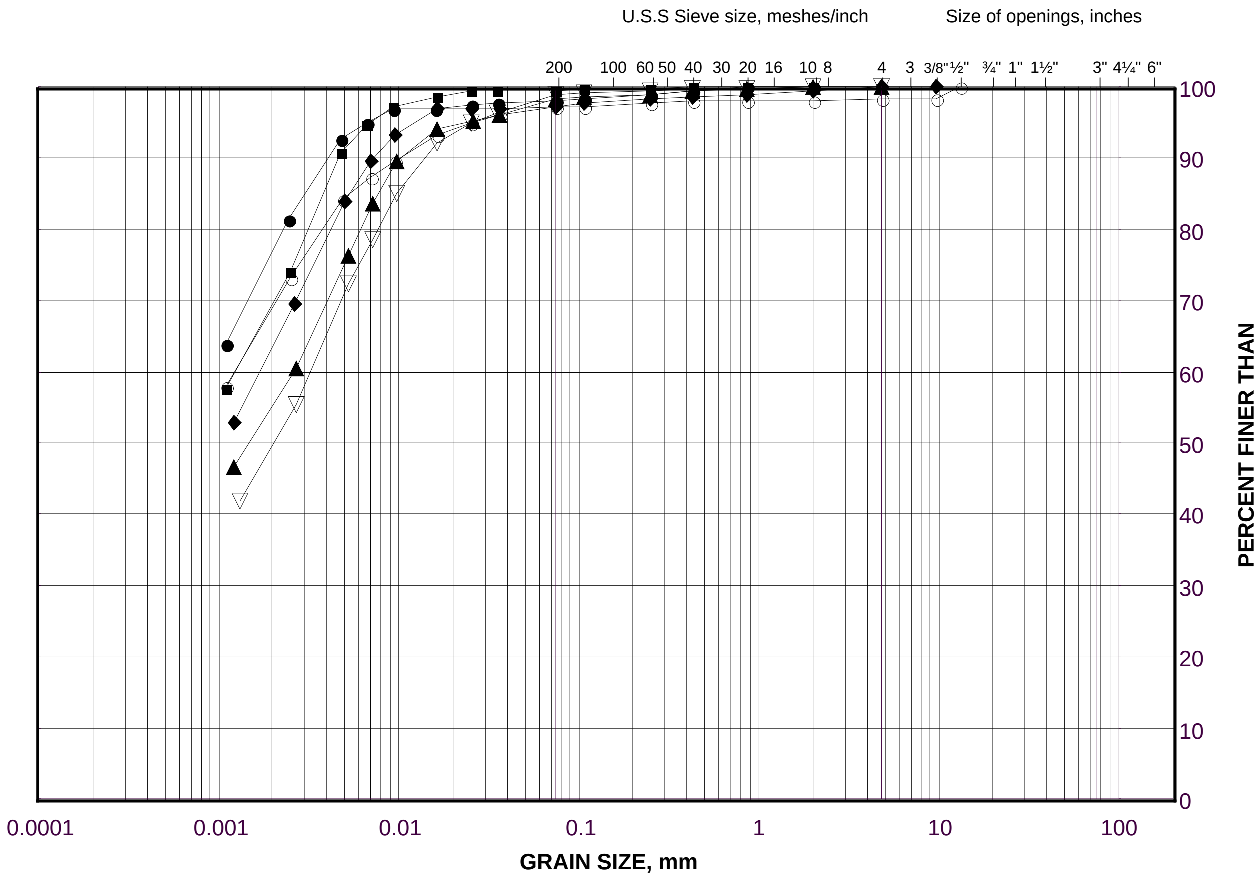
Figure No. A-3

Project No. 18105193

Checked By: SMM

GRAIN SIZE DISTRIBUTION
Silty Clay to Clay (Crust)
(Culvert Site No. 34-458/C)

FIGURE A-4



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

LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	458-1	2	177.7
■	458-3	3	177.6
◆	458-4	4	176.7
▲	458-2	4	177.0
▽	458-3	5	176.1
❍	458-1	6	174.6

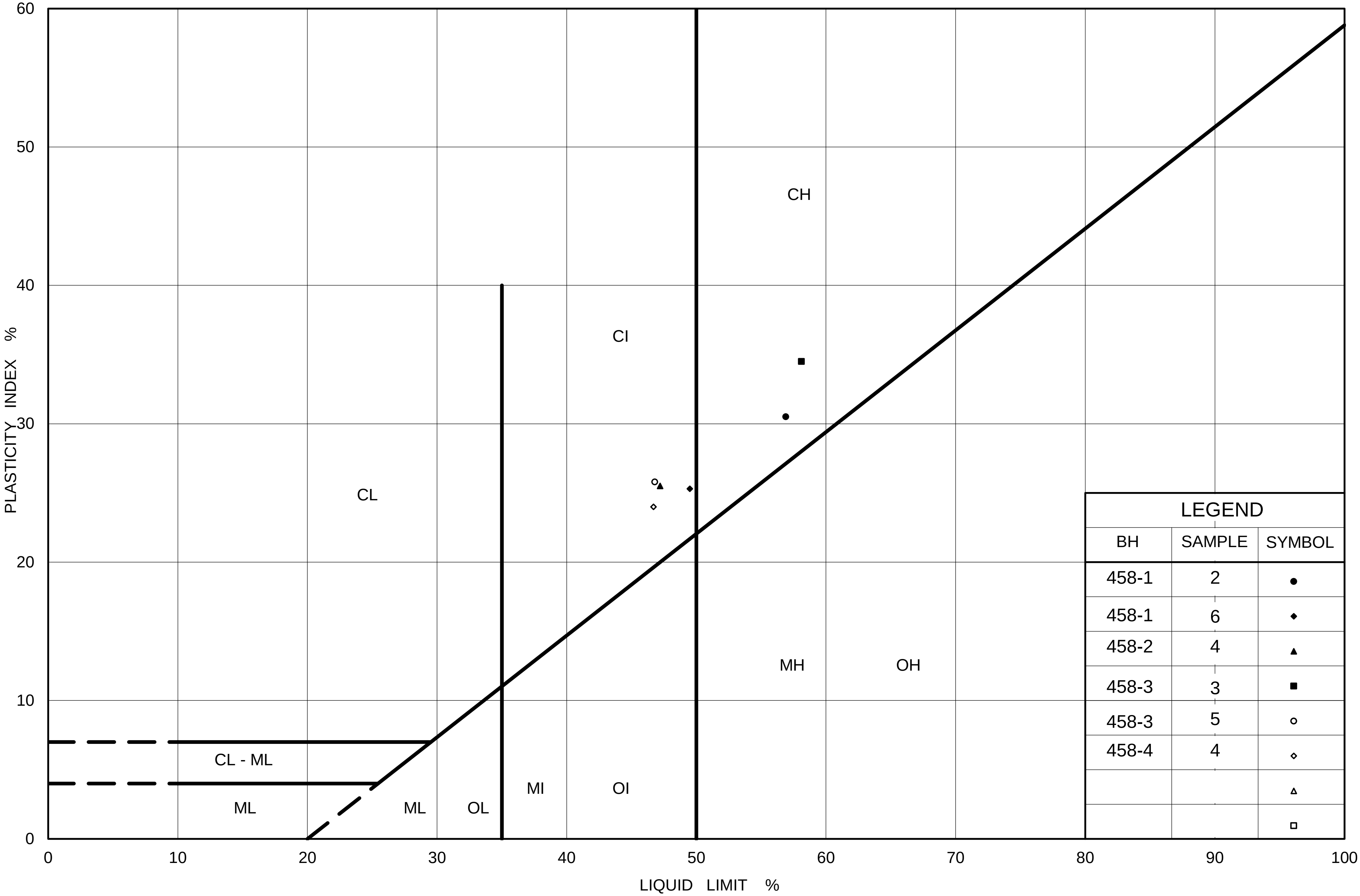
Project Number: 18105193

Checked By: SMM

Golder Associates

Date: 08-May-19

Oct 75, FF-S-21



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PLASTICITY CHART
Silty Clay to Clay (Crust)
(Culvert Site No. 34-458/C)

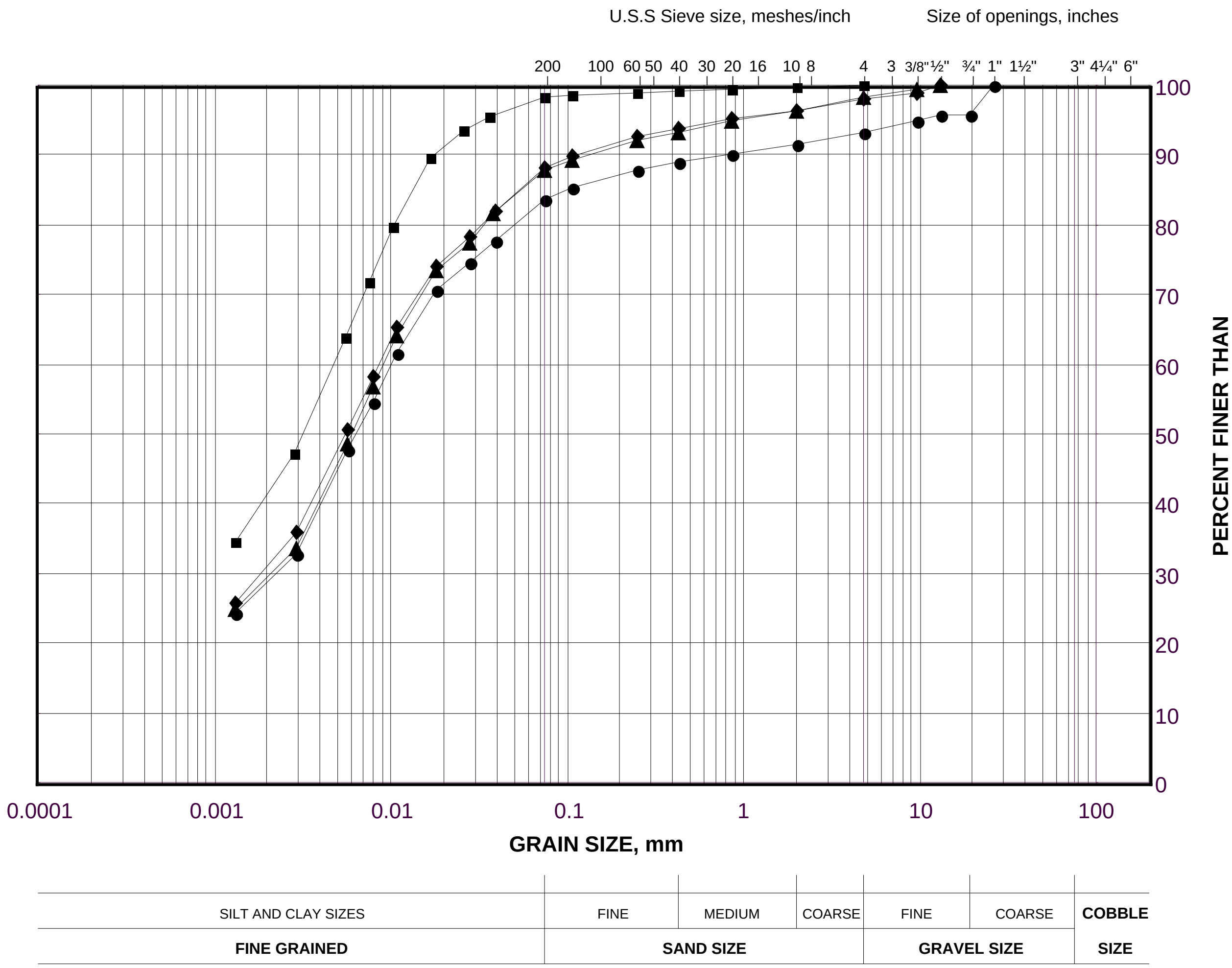
Figure No. A-5

Project No. 18105193

Checked By: SMM

GRAIN SIZE DISTRIBUTION
Clayey Silt
(Culvert Site No. 34-326/C)

FIGURE A-6A



LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	326-3	10	168.6
■	326-3	12	165.5
◆	326-1	7	170.2
▲	326-2	9	170.0

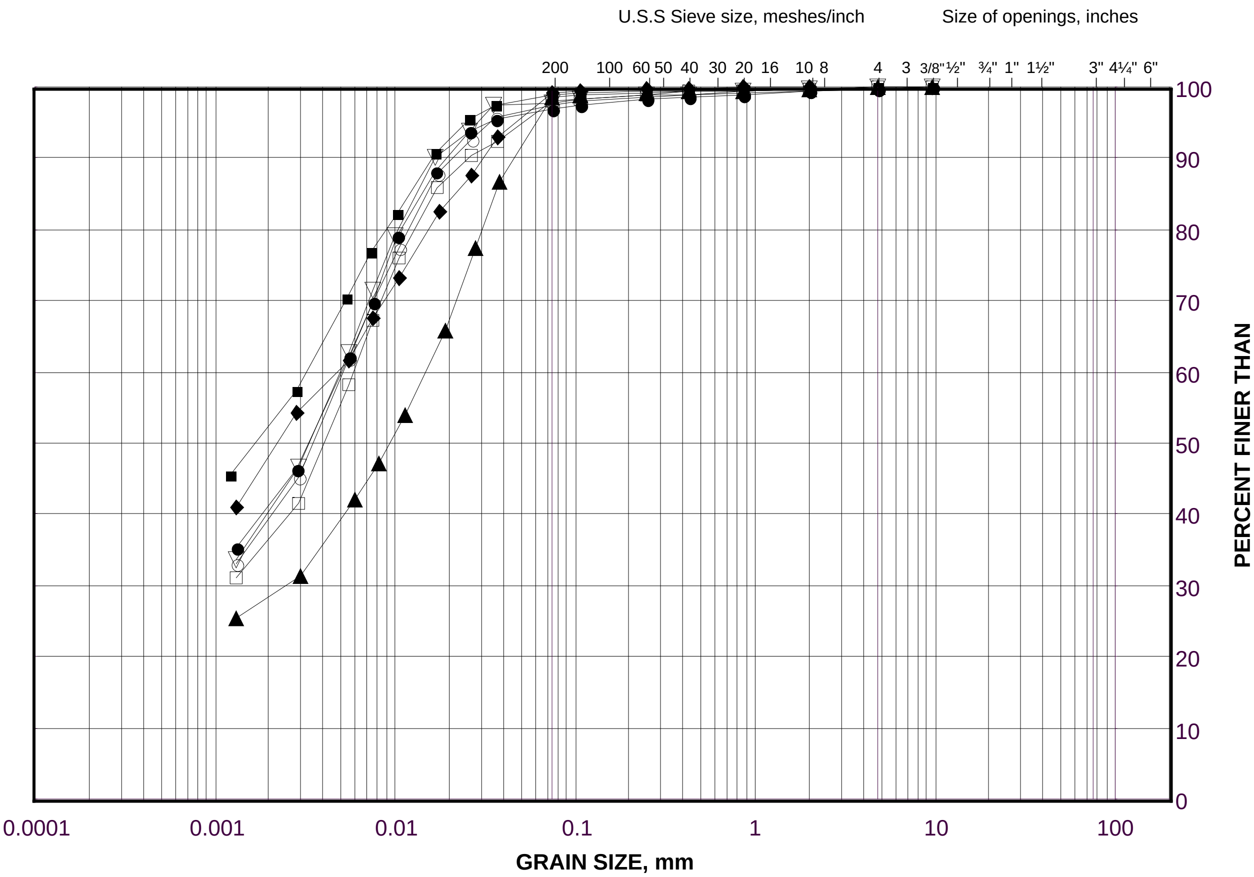
Project Number: 18105193

Checked By: SMM

Golder Associates

Date: 08-May-19

GRAIN SIZE DISTRIBUTION Clayey Silt to Silty Clay (Culvert Site No. 34-458/C)	FIGURE A-6B



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

LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	458-1	11	166.2
■	458-4	12	165.2
◆	458-2	12	165.6
▲	458-3	12	165.4
▽	458-4	7	172.9
❍	458-1	8	170.8
☐	458-2	8	171.7

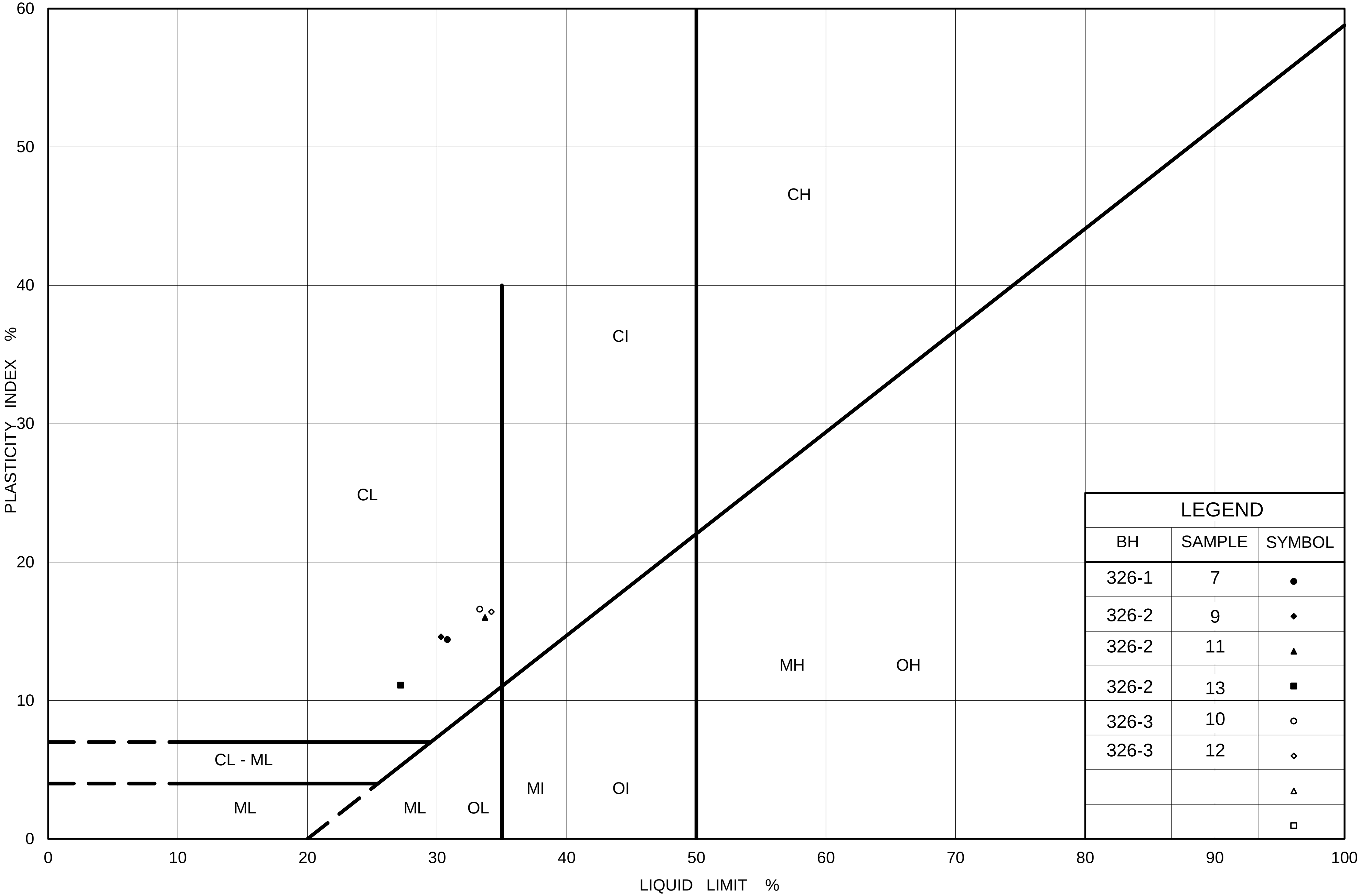
Project Number: 18105193

Checked By: SMM

Golder Associates

Date: 08-May-19

Oct 75, FF-S-21



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PLASTICITY CHART

Clayey Silt

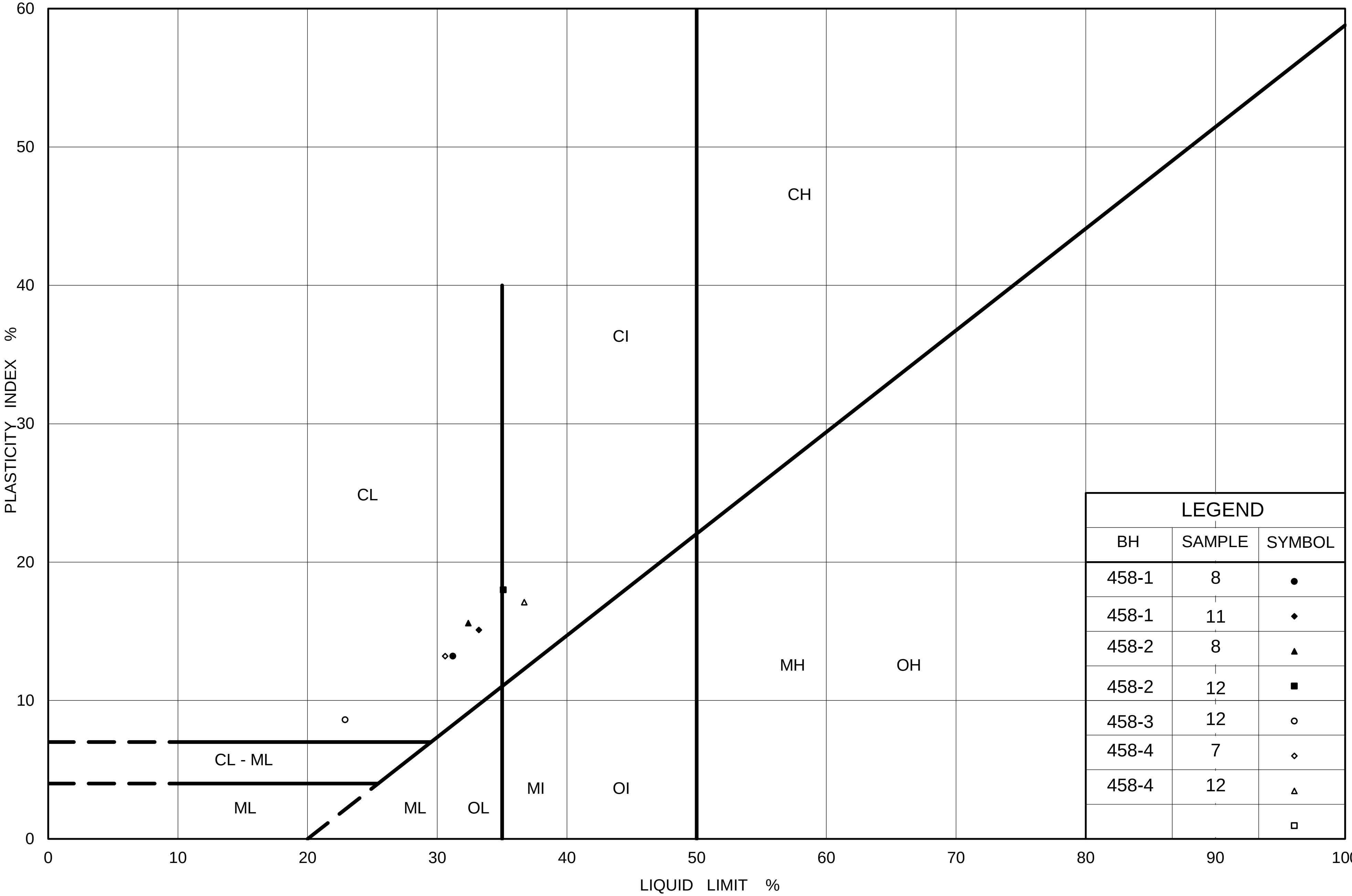
(Culvert Site No. 34-326/C)

Figure No. A-7A

Project No. 18105193

Checked By: SMM

Oct 75, FF-S-21



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PLASTICITY CHART
Clayey Silt to Silty Clay
(Culvert Site No. 34-458/C)

Figure No. A-7B

Project No. 18105193

Checked By: SMM

APPENDIX B

Record of Borehole, Drillhole and Test Pit Sheets and Geotechnical Laboratory Results for Culvert Site No. 34-331/C

RECORD OF BOREHOLE No 331-1

SHEET 1 OF 1 **METRIC**

PROJECT 18105193
G.W.P. 2374-15-00
DIST Central HWY 140
DATUM Geodetic
LOCATION N 4750461.7; E 330386.1 MTM NAD 83 ZONE 10 (LAT. 42.893513; LONG. -79.186731)
BOREHOLE TYPE Power Auger, 70 mm I.D. Hollow Stem Augers
DATE January 11 and 14, 2019
ORIGINATED BY KN
COMPILED BY SE
CHECKED BY AJS

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
179.3	GROUND SURFACE				
0.0	ASPHALT (150 mm)				
0.2	Sand and gravel (FILL)				
178.7	Sandy clayey silt, trace to some gravel, trace rootlets (FILL) Stiff Brown Moist	1A	SS	12	
178.3 / 1.0	CLAYEY SILT, trace sand, trace gravel, trace silt pockets, trace sand pockets Stiff to very stiff Brown Moist	1B			
		2	SS	11	
		3	SS	21	
		4	SS	19	
		5A	SS	14	4 23 57 16
175.1 / 4.3	Sandy CLAYEY SILT, trace gravel, (TILL) Stiff Brown Moist	5B			
	LIMESTONE (BEDROCK) Grey Bedrock cored from a depth of 4.3 m to 7.5 m For bedrock coring details, refer to Record of Drillhole 331-1.	1	RC	REC 100%	RQD = 98%
		2	RC	REC 99%	RQD = 91%
171.8 / 7.5	END OF BOREHOLE				

Elevation scale: 179, 178, 177, 176, 175, 174, 173, 172

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 (%): 10 20 30
Unit weight γ kN/m³

NOTE:

1. Bedrock cored on January 14, 2019, from a drillhole advanced approximately 1 m east of the borehole location.

2. Borehole dry upon completion of soil drilling.

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

PROJECT: 18105193

RECORD OF DRILLHOLE: 331-1

SHEET 1 OF 1

LOCATION: N 4750461.70 ;E 330386.08

DRILLING DATE: January 14, 2019

DATUM: Geodetic

INCLINATION: -90° AZIMUTH: ---

DRILL RIG: CME 55 Truck

DRILLING CONTRACTOR: Geo-Environmental

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.	DISCONTINUITY DATA: TYPE AND SURFACE DESCRIPTION	FEATURES / PIEZOMETER
		Continued from Record of Borehole 331-1	175.03			
5	Rotary Drill HQ Core	Fresh, thinly bedded, grey, very fine to fine grained, non-porous to faintly porous, strong, LIMESTONE (Onondaga Formation)	4.29	1	JN,IR,RO,CC,CL JN,IR,RO,PC,CL BD,UN,RO,SO	UCS = 72.4 MPa
6–7				2	FR,UN,,SM BD,IR,SM,PC,CL BD,UN,RO,SO,CL BD,UN,RO BD,UN,SM BD,UN,SM BD,UN,SM	Lost core
			171.85 7.47			
		END OF DRILLHOLE				

DEPTH SCALE 1 : 50

GOLDER

LOGGED: KN

CHECKED: SE

GTA-RCK 046 S:\CLIENTS\MTO\HWY_140\02_DATA\GINT\HWY_140.GPJ GAL-MISS.GDT 19-7-10

RECORD OF BOREHOLE No 331-2

SHEET 1 OF 1 **METRIC**

PROJECT 18105193
G.W.P. 2374-15-00
LOCATION N 4750466.1; E 330399.0 MTM NAD 83 ZONE 10 (LAT. 42.893553; LONG. -79.186572)
ORIGINATED BY KN
DIST Central HWY 140
BOREHOLE TYPE Power Auger, 70 mm I.D. Hollow Stem Augers
COMPILED BY SE
DATUM Geodetic
DATE January 11 and 14, 2019
CHECKED BY AJS

ELEV / DEPTH	DESCRIPTION (SOIL PROFILE)	NUMBER	TYPE	"N" VALUES	WATER CONTENT / PLOT	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
179.3	GROUND SURFACE					
0.0	ASPHALT (130 mm)					
0.1	Sand and gravel (FILL), Compact, Grey, Moist					
178.3 / 1.0	Clayey silt, some sand, some gravel (FILL), Very stiff, Brown-black, Moist	1A / 1B	SS	16	w ≈ 5%	
177.8 / 1.5	CLAYEY SILT, trace sand, trace gravel, Stiff to very stiff, Brown, mottled grey, Moist	2	SS	14		
		3	SS	21	wP–wL plotted (approx. 15–31)	1 1 61 37
		4	SS	22		
175.6 / 3.7	Sandy CLAYEY SILT, trace gravel (TILL), Very stiff, Brown, Moist	5	SS	16	w ≈ 13%	
174.9 / 4.4	LIMESTONE (BEDROCK), Grey. Bedrock cored from a depth of 4.4 m to 7.5 m. For bedrock coring details, refer to Record of Drillhole 331-2.	6	SS	50/0.0		
		1	RC	REC 100%		RQD = 84%
		2	RC	REC 99%		RQD = 91%
171.8 / 7.5	END OF BOREHOLE					

NOTE:

1. Augers grinding and split-spoon refusal at 4.4 m depth.

2. Bedrock cored on January 14, 2019, from a drillhole advanced approximately 0.3 m south west of the borehole location.

3. Borehole dry upon completion of soil drilling.

Elevation scale: 179, 178, 177, 176, 175, 174, 173, 172

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 (%) 10 20 30; UNIT WEIGHT γ kN/m³

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

PROJECT: 18105193

RECORD OF DRILLHOLE: 331-2

SHEET 1 OF 1

LOCATION: N 4750466.15 ;E 330399.03

DRILLING DATE: January 14, 2019

DATUM: Geodetic

INCLINATION: -90° AZIMUTH: ---

DRILL RIG: CME 55 Truck

DRILLING CONTRACTOR: Geo- Environmental

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.	DISCONTINUITY DATA: TYPE AND SURFACE DESCRIPTION	FEATURES / PIEZOMETER
		Continued from Record of Borehole 331-2	174.90			
5–7	Rotary Drill, HQ Core	Fresh, thinly bedded, grey, very fine to fine grained, non-porous to faintly porous, strong, LIMESTONE (Onondaga Formation)	4.39	1	BD,PL,SM BD,UN,RO BD,UN,RO BD,UN,RO BD,ST,SM BD,UN,RO	
				2	BD,UN,RO FR,UN,RO,SA BD,UN,SM,SA	BC UCS = 74.5 MPa
			171.82 7.47			
		END OF DRILLHOLE				

Column headings: DEPTH SCALE METRES; DRILLING RECORD; DESCRIPTION; SYMBOLIC LOG; ELEV. DEPTH (m); RUN No.; FLUSH RETURN; RECOVERY (TOTAL CORE % 80 60 40 20; 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; TYPE AND SURFACE DESCRIPTION; Jr; Ja; Jcon); WEATHERING INDEX W1 W2 W3 W4 W5 W6; Diametral Point Load Index (MPa) 2 4 6; FEATURES; PIEZOMETER

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

GTA-RCK 046 S:\CLIENTS\MTO\HWY_140\02_DATA\GINT\HWY_140.GPJ GAL-MISS.GDT 19-7-10

DEPTH SCALE 1 : 50

GOLDER

LOGGED: KN

CHECKED: SE

GOLDER

Foundation Design

RECORD OF BOREHOLE No 331-3

SHEET 1 OF 1

METRIC

PROJECT 18105193

G.W.P. 2374-15-00

LOCATION N 4750469.8; E 330399.7 MTM NAD 83 ZONE 10 (LAT. 42.893577; LONG. -79.186564)

ORIGINATED BY KN

DIST Central HWY 140

BOREHOLE TYPE TEST PIT Manually Advanced

COMPILED BY EN

DATUM Geodetic

DATE March 21, 2019

CHECKED BY AJS

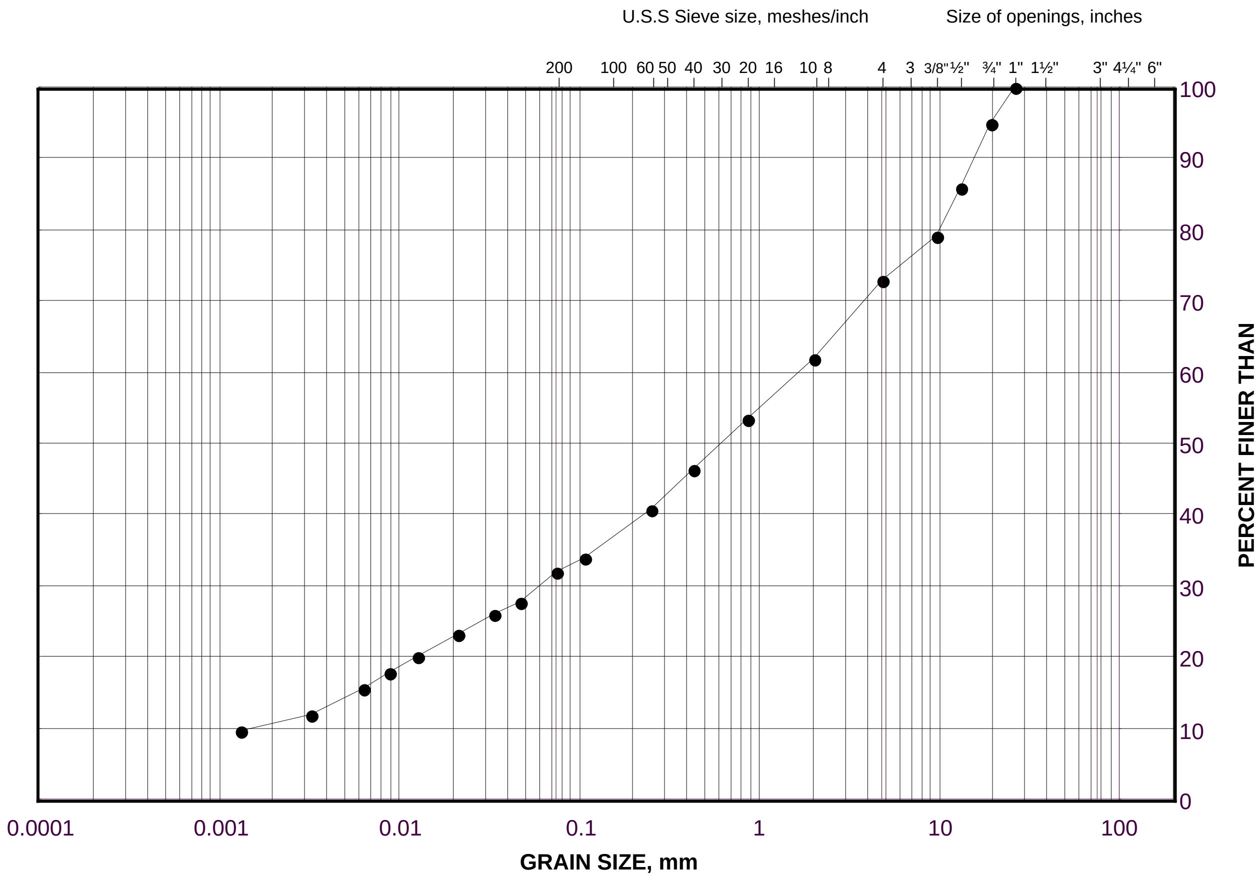
ELEV DEPTH	DESCRIPTION (SOIL PROFILE)	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa	WATER CONTENT (%) (w_P, w, w_L)	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
178.9	GROUND SURFACE													
~~0.0~~	TOPSOIL (100 mm)		1	-	-				w ≈ 22; w_P ≈ 25; w_L ≈ 40		28	40	21	11
0.2	Gravelly silty clay with sand, trace organics, cobbles (FILL) Brown Moist													
	END OF TEST PIT													

Legend: ○ UNCONFINED; + FIELD VANE; ● QUICK TRIAXIAL; × REMOULDED

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

GTA-MTO 001 S:\CLIENTS\MTO\HWY_140\02_DATA\GINT\HWY_140.GPJ GAL-GTA.GDT 07/10/19

GRAIN SIZE DISTRIBUTION Gravelly Silty Clay with Sand (FILL)	FIGURE B-1



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

LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	331-3	1	178.8

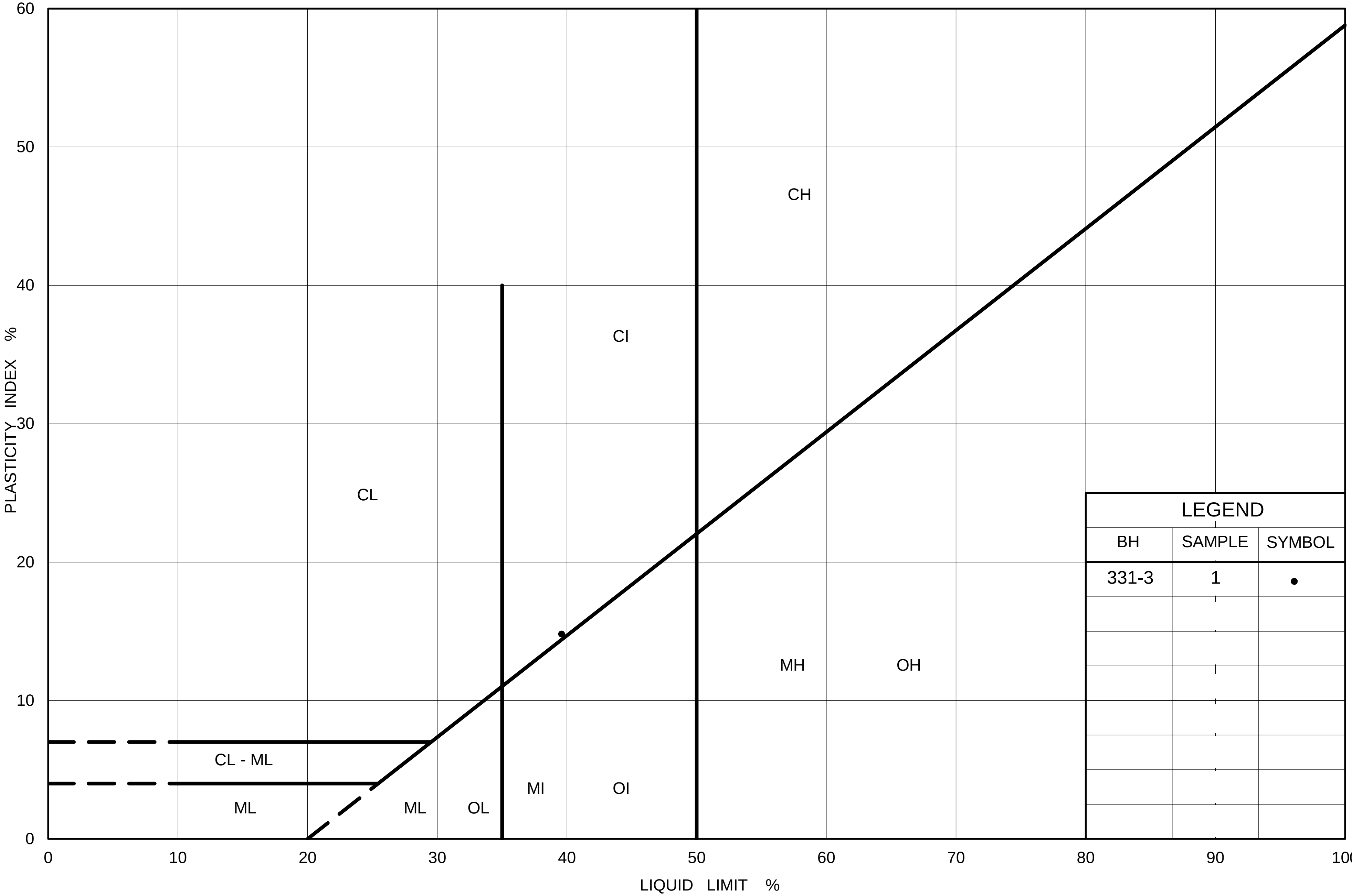
Project Number: 18105193

Checked By: SMM

Golder Associates

Date: 02-May-19

Oct 75, FF-S-21



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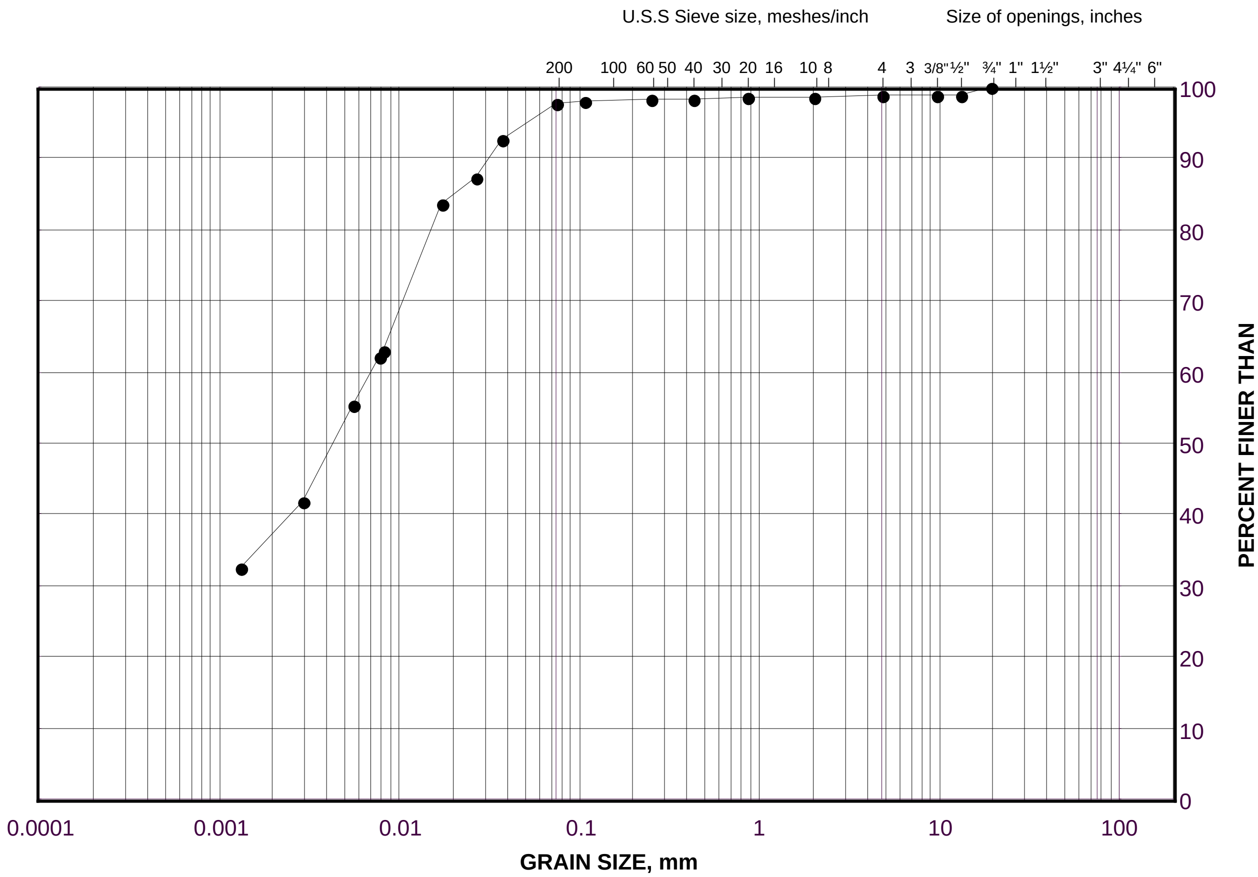
PLASTICITY CHART
Gravelly Silty Clay with Sand (FILL)

Figure No. B-2

Project No. 18105193

Checked By: SMM

GRAIN SIZE DISTRIBUTION Clayey Silt	FIGURE B-3



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

LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	331-2	3	176.7

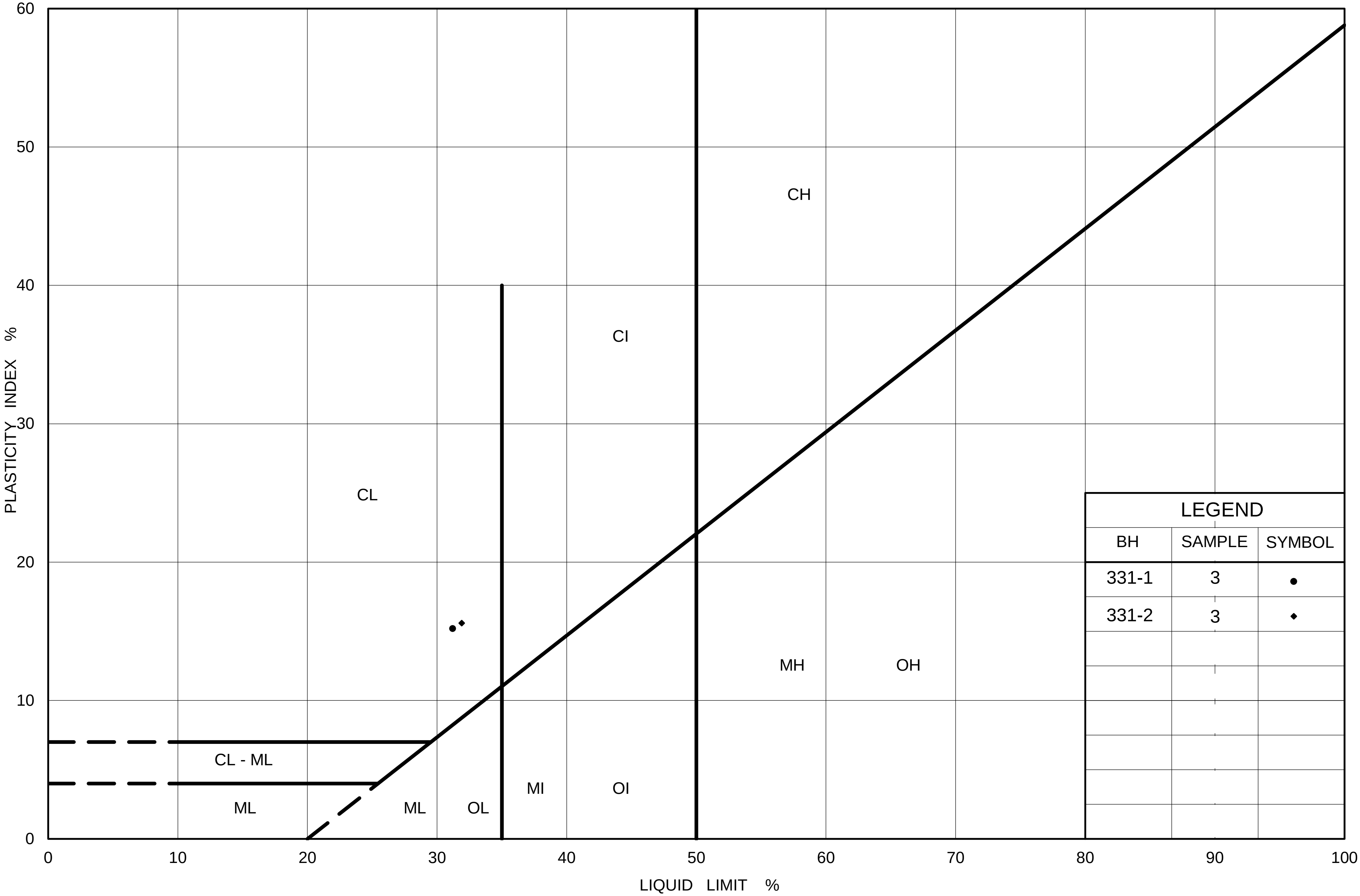
Project Number: 18105193

Checked By: SMM

Golder Associates

Date: 02-May-19

Oct 75, FF-S-21



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PLASTICITY CHART
Clayey Silt

Figure No. B-4

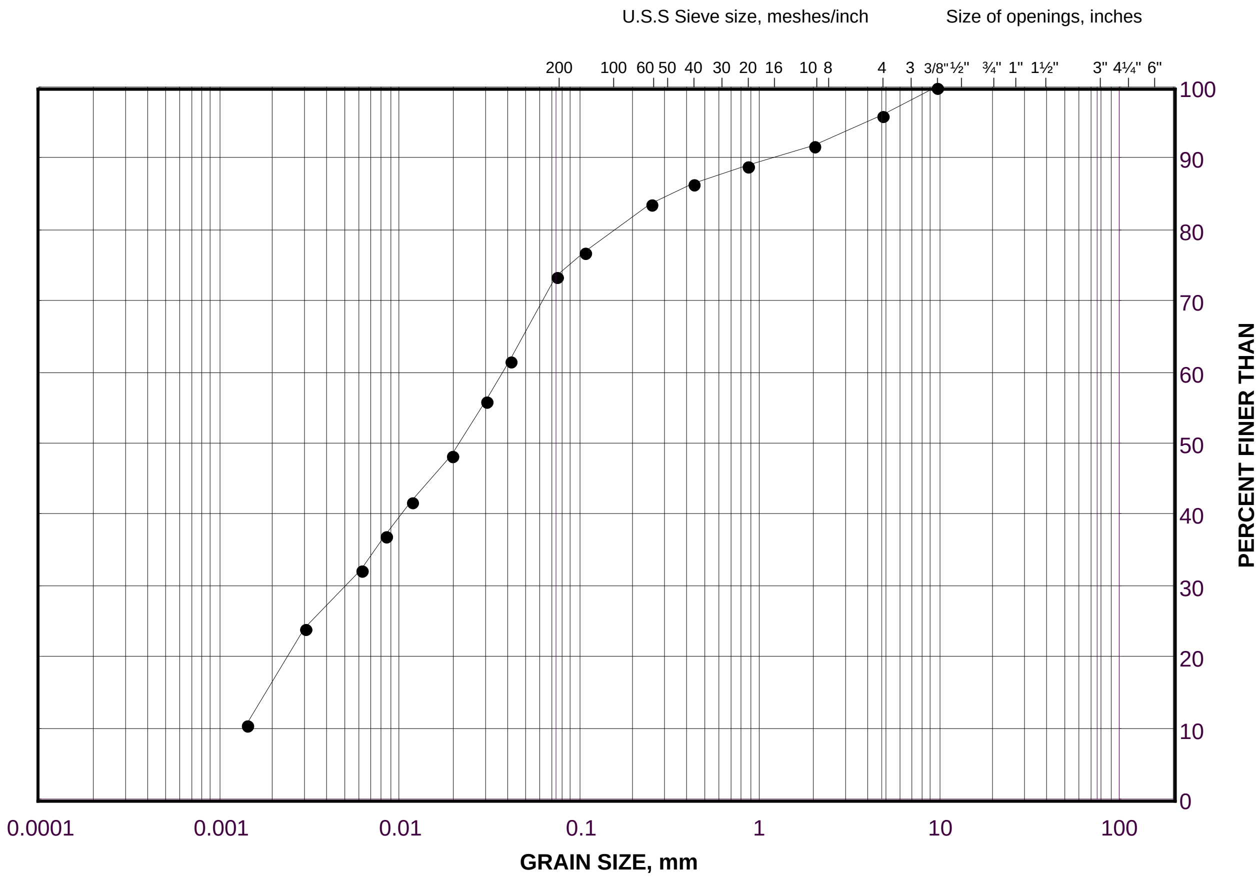
Project No. 18105193

Checked By: SMM

GRAIN SIZE DISTRIBUTION

Clayey Silt (TILL)

FIGURE B-5



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

LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	331-1	5B	175.2

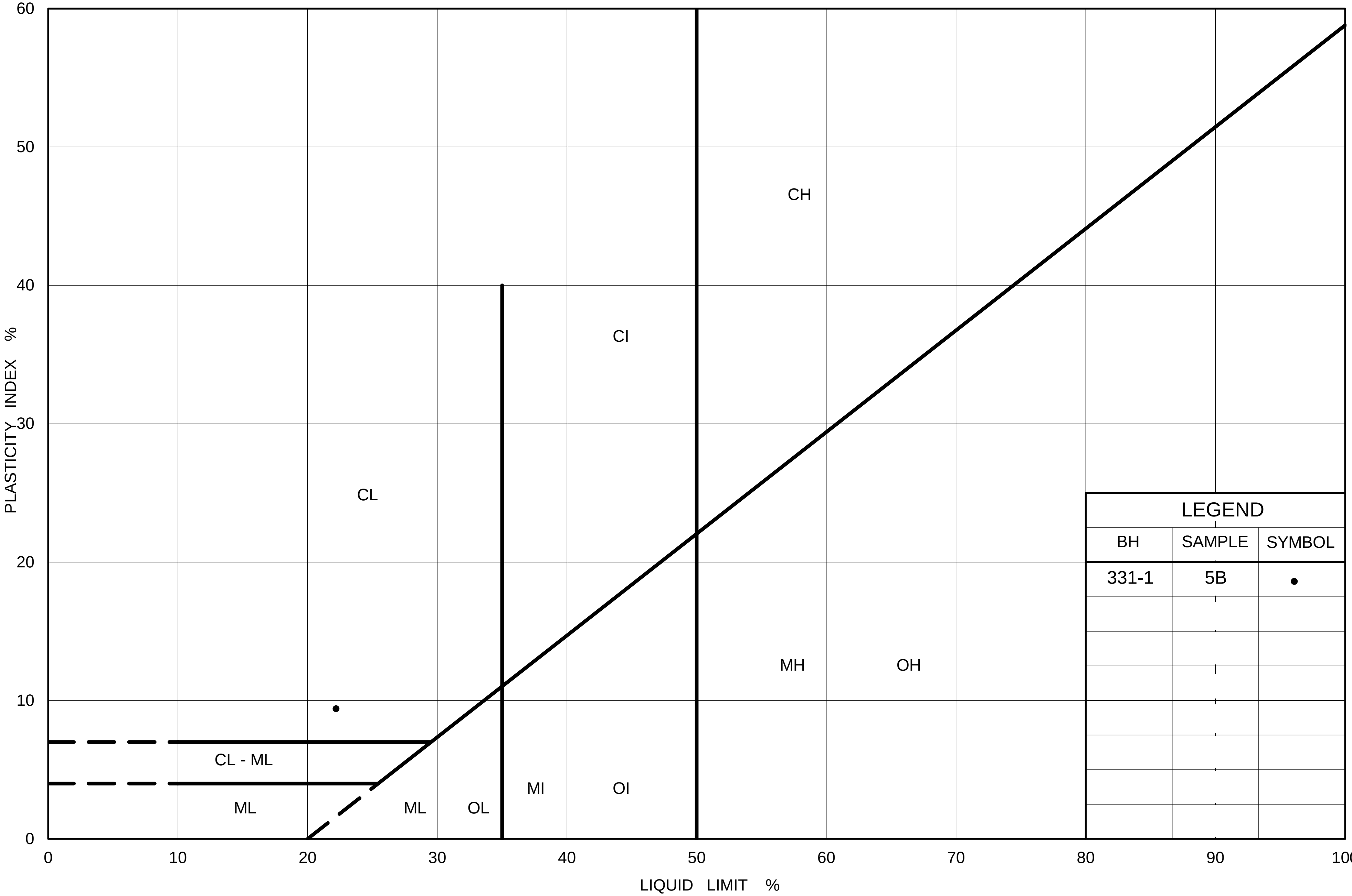
Project Number: 18105193

Checked By: SMM

Golder Associates

Date: 02-May-19

Oct 75, FF-S-21



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Ontario

PLASTICITY CHART
Clayey Silt (TILL)

Figure No. B-6

Project No. 18105193

Checked By: SMM

Start of Run No. 1 (4.29 m) Start of Run No. 2 (5.92 m)

End of Borehole (7.47 m)

Borehole 331-1: 4.29 m to 7.47 m

Start of Run No. 1 (4.39 m)

Start of Run No. 2 (5.92 m)

End of Borehole (7.47) m

Borehole 331-2: 4.39 m to 7.47 m

0 m | 0.25 m | 0.5 m | 0.75 m | 1.0 m | 1.25 m | 1.5 m

0 ft | 1 ft | 2 ft | 3 ft | 4 ft | 5 ft

Scale

PROJECT	**MTO G.W.P. 2374-15-00** **Culvert Replacements At** **Highway 3, 140, Niagara Region**
TITLE	**Bedrock Core Photographs** **Drillholes 331-1 and 331-2**

GOLDER

PROJECT No. 18105193			FILE No. ----	
DRAFT	KN	20190415	SCALE AS SHOWN	VER. 1.
CADD	--	--		
CHECK	SMM		**FIGURE B-7**	
REVIEW				

REVISION DATE: April 15, 2019 BY: KN Project: 18105193

FIGURE B-8A

UNCONFINED COMPRESSION TEST (UC) OF INTACT ROCK CORE SPECIMENS

ASTM D7012

SAMPLE IDENTIFICATION

PROJECT NUMBER	18105193	SAMPLE NUMBER	UCS 1
PROJECT NAME	AIA /2017-E-0068 hwy 3 58 140 Niaga	SAMPLE DEPTH, m	4.29-4.48
BOREHOLE NUMBER	331-1	DATE:	2019-02-04

TEST CONDITIONS

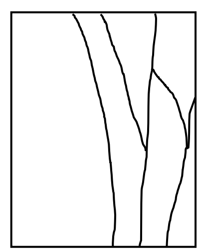
MACHINE SPEED, mm/min	N/A	TYPE OF SPECIMEN	Rock Core
DURATION OF TEST,min	>2 <15	L/D	2.30

SPECIMEN INFORMATION

SAMPLE HEIGHT, cm	14.63	WATER CONTENT, (specimen) %	0.20
SAMPLE DIAMETER, cm	6.35	UNIT WEIGHT, kN/m^3	26.81
SAMPLE AREA, cm^2	31.66	DRY UNIT WT., kN/m^3	26.76
SAMPLE VOLUME, cm^3	463.08	SPECIFIC GRAVITY	-
WET WEIGHT, g	1266.50	VOID RATIO	-
DRY WEIGHT, g	1263.97		

VISUAL INSPECTION

FAILURE SKETCH



TEST RESULTS

STRAIN AT FAILURE, %	N/A	COMPRESSIVE STRENGTH, MPa	72.4

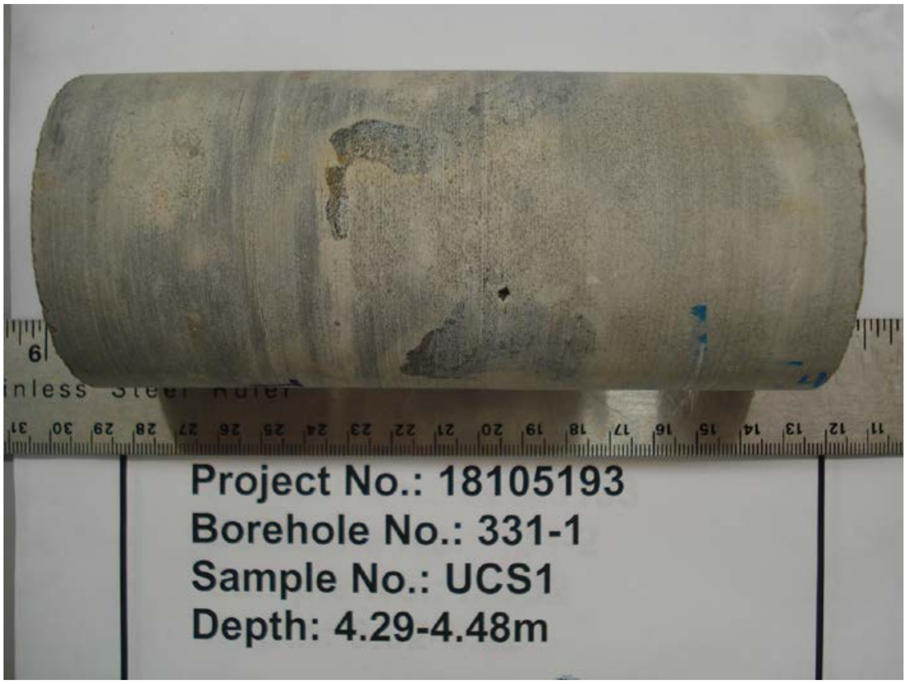
REMARKS:

Checked By:

Golder Associates

UNCONFINED COMPRESSION TEST (UC) OF INTACT ROCK CORE SPECIMENS
ASTM D7012

FIGURE B-8B



BEFORE COMPRESSION

AFTER COMPRESSION

Date Feb. 7, 2019
Project 18105193

Golder Associates

Drawn Frank
Chkd. MM

UNCONFINED COMPRESSION TEST (UC) OF INTACT ROCK CORE SPECIMENS
ASTM D7012

SAMPLE IDENTIFICATION

PROJECT NUMBER	18105193	SAMPLE NUMBER	UCS 2
PROJECT NAME	AIA /2017-E-0068 hwy 3 58 140 Niaga	SAMPLE DEPTH, m	6.02-6.22
BOREHOLE NUMBER	331-2	DATE:	2019-02-04

TEST CONDITIONS

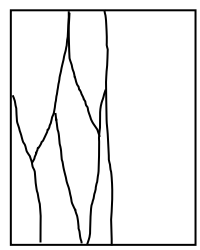
MACHINE SPEED, mm/min	N/A	TYPE OF SPECIMEN	Rock Core
DURATION OF TEST,min	>2 <15	L/D	2.26

SPECIMEN INFORMATION

SAMPLE HEIGHT, cm	14.31	WATER CONTENT, (specimen) %	0.10
SAMPLE DIAMETER, cm	6.35	UNIT WEIGHT, kN/m^3	27.37
SAMPLE AREA, cm^2	31.63	DRY UNIT WT., kN/m^3	27.34
SAMPLE VOLUME, cm^3	452.71	SPECIFIC GRAVITY	-
WET WEIGHT, g	1264.01	VOID RATIO	-
DRY WEIGHT, g	1262.75		

VISUAL INSPECTION

FAILURE SKETCH



TEST RESULTS

STRAIN AT FAILURE, %	N/A	COMPRESSIVE STRENGTH, MPa	74.5

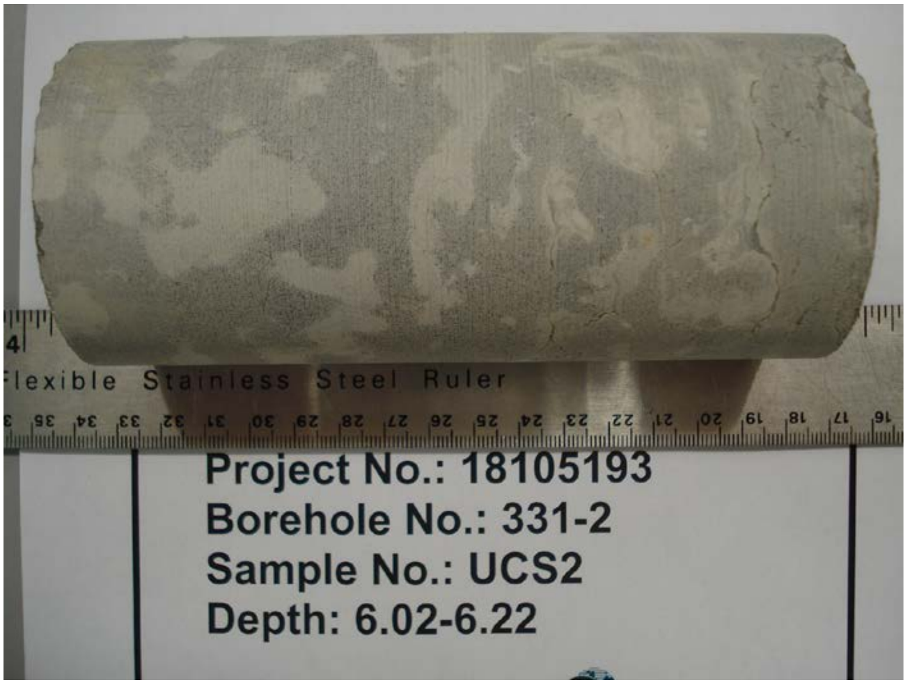
REMARKS:

Checked By:

Golder Associates

UNCONFINED COMPRESSION TEST (UC) OF INTACT ROCK CORE SPECIMENS
ASTM D7012

FIGURE B-9B



BEFORE COMPRESSION

AFTER COMPRESSION

Date Feb. 7, 2019
Project 18105193

Golder Associates

Drawn Frank
Chkd. MM

APPENDIX C

Analytical Laboratory Test Results (Maxxam Analytics)

Your Project #: 18105193
Site Location: HWY 3, 58, 140 NIAGARA
Your C.O.C. #: 122132

Attention: Alex Szot

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

Report Date: 2019/02/05
Report #: R5583500
Version: 1 - Final

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B924885
Received: 2019/01/29, 12:40

Sample Matrix: Soil
Samples Received: 6

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Reference
Chloride (20:1 extract)	6	N/A	2019/02/04	CAM SOP-00463	EPA 325.2 m
Conductivity	6	N/A	2019/02/01	CAM SOP-00414	OMOE E3530 v1 m
pH CaCl2 EXTRACT	6	2019/02/01	2019/02/01	CAM SOP-00413	EPA 9045 D m
Resistivity of Soil	6	2019/01/29	2019/02/01	CAM SOP-00414	SM 23 2510 m
Sulphate (20:1 Extract)	6	N/A	2019/02/04	CAM SOP-00464	EPA 375.4 m

Remarks:

Maxxam Analytics' laboratories are accredited to ISO/IEC 17025:2005 for specific parameters on scopes of accreditation. Unless otherwise noted, procedures used by Maxxam are based upon recognized Provincial, Federal or US method compendia such as CCME, MDDELCC, EPA, APHA.

All work recorded herein has been done in accordance with procedures and practices ordinarily exercised by professionals in Maxxam's profession using accepted testing methodologies, quality assurance and quality control procedures (except where otherwise agreed by the client and Maxxam in writing). All data is in statistical control and has met quality control and method performance criteria unless otherwise noted. All method blanks are reported; unless indicated otherwise, associated sample data are not blank corrected. Where applicable, unless otherwise noted, Measurement Uncertainty has not been accounted for when stating conformity to the referenced standard.

Maxxam Analytics' liability is limited to the actual cost of the requested analyses, unless otherwise agreed in writing. There is no other warranty expressed or implied. Maxxam has been retained to provide analysis of samples provided by the Client using the testing methodology referenced in this report. Interpretation and use of test results are the sole responsibility of the Client and are not within the scope of services provided by Maxxam, unless otherwise agreed in writing. Maxxam is not responsible for the accuracy or any data impacts, that result from the information provided by the customer or their agent.

Solid sample results, except biota, are based on dry weight unless otherwise indicated. Organic analyses are not recovery corrected except for isotope dilution methods.
Results relate to samples tested. When sampling is not conducted by Maxxam, results relate to the supplied samples tested.
This Certificate shall not be reproduced except in full, without the written approval of the laboratory.
Reference Method suffix "m" indicates test methods incorporate validated modifications from specific reference methods to improve performance.
* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.

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Your Project #: 18105193
Site Location: HWY 3, 58, 140 NIAGARA
Your C.O.C. #: 122132

Attention: Alex Szot

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

Report Date: 2019/02/05
Report #: R5583500
Version: 1 - Final

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B924885
Received: 2019/01/29, 12:40

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.
Ema Gitej, Senior Project Manager
Email: EGitej@maxxam.ca
Phone# (905)817-5829
==
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Maxxam Job #: B924885
Report Date: 2019/02/05

Golder Associates Ltd
Client Project #: 18105193
Site Location: HWY 3, 58, 140 NIAGARA
Sampler Initials: KN

SOIL CORROSIVITY PACKAGE (SOIL)

Maxxam ID		IWC430		IWC431		IWC432	IWC433		IWC434		
Sampling Date		2019/01/08		2019/01/15		2019/01/11	2019/01/11		2019/01/10		
COC Number		122132		122132		122132	122132		122132		
	UNITS	**458-3 SS6**	**RDL**	**326-3 SS4**	**RDL**	**331-2 SS5**	**331-1 SS4**	**RDL**	**458-2 SS5**	**RDL**	**QC Batch**
Calculated Parameters											
Resistivity	ohm-cm	1300		1000		3200	700		430		5950491
Inorganics											
Soluble (20:1) Chloride (Cl-)	ug/g	330	20	76	20	82	710	20	58	20	5956167
Conductivity	umho/cm	794	2	966	2	312	1420	2	2340	2	5955891
Available (CaCl2) pH	pH	7.78		7.73		7.81	7.82		7.83		5956055
Soluble (20:1) Sulphate (SO4)	ug/g	220	20	810	40	61	120	20	3600	100	5956190

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam ID		IWC434			IWC436		
Sampling Date		2019/01/10			2019/01/16		
COC Number		122132			122132		
	UNITS	**458-2 SS5 Lab-Dup**	**RDL**	**QC Batch**	**326-2 SS3**	**RDL**	**QC Batch**
Calculated Parameters							
Resistivity	ohm-cm				670		5950491
Inorganics							
Soluble (20:1) Chloride (Cl-)	ug/g				410	20	5956167
Conductivity	umho/cm	2290	2	5955891	1490	2	5955891
Available (CaCl2) pH	pH				7.70		5956055
Soluble (20:1) Sulphate (SO4)	ug/g				830	40	5956190

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch
Lab-Dup = Laboratory Initiated Duplicate

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Maxxam
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Maxxam Job #: B924885
Report Date: 2019/02/05

Golder Associates Ltd
Client Project #: 18105193
Site Location: HWY 3, 58, 140 NIAGARA
Sampler Initials: KN

TEST SUMMARY

Maxxam ID: IWC430
Sample ID: 458-3 SS6
Matrix: Soil

Collected: 2019/01/08
Shipped:
Received: 2019/01/29

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	5956167	N/A	2019/02/04	Deonarine Ramnarine
Conductivity	AT	5955891	N/A	2019/02/01	Kazzandra Adeva
pH CaCl2 EXTRACT	AT	5956055	2019/02/01	2019/02/01	Gnana Thomas
Resistivity of Soil		5950491	2019/02/01	2019/02/01	Ewa Pranjic
Sulphate (20:1 Extract)	KONE/EC	5956190	N/A	2019/02/04	Alina Dobreanu

Maxxam ID: IWC431
Sample ID: 326-3 SS4
Matrix: Soil

Collected: 2019/01/15
Shipped:
Received: 2019/01/29

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	5956167	N/A	2019/02/04	Deonarine Ramnarine
Conductivity	AT	5955891	N/A	2019/02/01	Kazzandra Adeva
pH CaCl2 EXTRACT	AT	5956055	2019/02/01	2019/02/01	Gnana Thomas
Resistivity of Soil		5950491	2019/02/01	2019/02/01	Ewa Pranjic
Sulphate (20:1 Extract)	KONE/EC	5956190	N/A	2019/02/04	Alina Dobreanu

Maxxam ID: IWC432
Sample ID: 331-2 SS5
Matrix: Soil

Collected: 2019/01/11
Shipped:
Received: 2019/01/29

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	5956167	N/A	2019/02/04	Deonarine Ramnarine
Conductivity	AT	5955891	N/A	2019/02/01	Kazzandra Adeva
pH CaCl2 EXTRACT	AT	5956055	2019/02/01	2019/02/01	Gnana Thomas
Resistivity of Soil		5950491	2019/02/01	2019/02/01	Ewa Pranjic
Sulphate (20:1 Extract)	KONE/EC	5956190	N/A	2019/02/04	Alina Dobreanu

Maxxam ID: IWC433
Sample ID: 331-1 SS4
Matrix: Soil

Collected: 2019/01/11
Shipped:
Received: 2019/01/29

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	5956167	N/A	2019/02/04	Deonarine Ramnarine
Conductivity	AT	5955891	N/A	2019/02/01	Kazzandra Adeva
pH CaCl2 EXTRACT	AT	5956055	2019/02/01	2019/02/01	Gnana Thomas
Resistivity of Soil		5950491	2019/02/01	2019/02/01	Ewa Pranjic
Sulphate (20:1 Extract)	KONE/EC	5956190	N/A	2019/02/04	Alina Dobreanu

Maxxam ID: IWC434
Sample ID: 458-2 SS5
Matrix: Soil

Collected: 2019/01/10
Shipped:
Received: 2019/01/29

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	5956167	N/A	2019/02/04	Deonarine Ramnarine
Conductivity	AT	5955891	N/A	2019/02/01	Kazzandra Adeva

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Maxxam Job #: B924885
Report Date: 2019/02/05

Golder Associates Ltd
Client Project #: 18105193
Site Location: HWY 3, 58, 140 NIAGARA
Sampler Initials: KN

TEST SUMMARY

Maxxam ID: IWC434
Sample ID: 458-2 SS5
Matrix: Soil

Collected: 2019/01/10
Shipped:
Received: 2019/01/29

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
pH CaCl2 EXTRACT	AT	5956055	2019/02/01	2019/02/01	Gnana Thomas
Resistivity of Soil		5950491	2019/02/01	2019/02/01	Ewa Pranjic
Sulphate (20:1 Extract)	KONE/EC	5956190	N/A	2019/02/04	Alina Dobreanu

Maxxam ID: IWC434 Dup
Sample ID: 458-2 SS5
Matrix: Soil

Collected: 2019/01/10
Shipped:
Received: 2019/01/29

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Conductivity	AT	5955891	N/A	2019/02/01	Kazzandra Adeva

Maxxam ID: IWC436
Sample ID: 326-2 SS3
Matrix: Soil

Collected: 2019/01/16
Shipped:
Received: 2019/01/29

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	5956167	N/A	2019/02/04	Deonarine Ramnarine
Conductivity	AT	5955891	N/A	2019/02/01	Kazzandra Adeva
pH CaCl2 EXTRACT	AT	5956055	2019/02/01	2019/02/01	Gnana Thomas
Resistivity of Soil		5950491	2019/02/01	2019/02/01	Ewa Pranjic
Sulphate (20:1 Extract)	KONE/EC	5956190	N/A	2019/02/04	Alina Dobreanu

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GENERAL COMMENTS

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

Package 1	7.7°C

Sample 326-1 SS3 has not been analyzed as per client request.

Results relate only to the items tested.

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Maxxam Job #: B924885
Report Date: 2019/02/05

QUALITY ASSURANCE REPORT

Golder Associates Ltd
Client Project #: 18105193
Site Location: HWY 3, 58, 140 NIAGARA
Sampler Initials: KN

			Matrix Spike		SPIKED BLANK		Method Blank		RPD	
QC Batch	Parameter	Date	% Recovery	QC Limits	% Recovery	QC Limits	Value	UNITS	Value (%)	QC Limits
5955891	Conductivity	2019/02/01			103	90 - 110	<2	umho/cm	2.2	10
5956055	Available (CaCl2) pH	2019/02/01			100	97 - 103			1.7	N/A
5956167	Soluble (20:1) Chloride (Cl-)	2019/02/04	108	70 - 130	101	70 - 130	<20	ug/g	NC	35
5956190	Soluble (20:1) Sulphate (SO4)	2019/02/04	NC	70 - 130	99	70 - 130	<20	ug/g	2.4	35

N/A = Not Applicable

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

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

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

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

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

NC (Duplicate RPD): The duplicate RPD was not calculated. The concentration in the sample and/or duplicate was too low to permit a reliable RPD calculation (absolute difference <= 2x RDL).

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Maxxam Job #: B924885
Report Date: 2019/02/05

Golder Associates Ltd
Client Project #: 18105193
Site Location: HWY 3, 58, 140 NIAGARA
Sampler Initials: KN

VALIDATION SIGNATURE PAGE

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

Ewa Pranjic, M.Sc., C.Chem, Scientific Specialist

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CAM FCD-01191/3

CHAIN OF CUSTODY RECORD 122132

Page ____ of ____

Invoice Information		Report Information (if differs from invoice)		Project Information (where applicable)		Turnaround Time (TAT) Required
Company Name:	Golder Associates	Company Name:	–	Quotation #:		[X] Regular TAT (5-7 days) Most analyses
Contact Name:	Alex Szot	Contact Name:		P.O. #/ AFE#:		PLEASE PROVIDE ADVANCE NOTICE FOR RUSH PROJECTS
Address:	6925 Century Ave, Suite 100, Mississauga, ON	Address:		Project #:	18105193	Rush TAT (Surcharges will be applied) [ ] 1 Day [ ] 2 Days [ ] 3-4 Days
				Site Location:	Hwy 3, 58, 140 Niagara	
Phone:	905 567 4444 Fax:	Phone:	Fax:	Site #:		Date Required:
Email:	Alex_Szot@golder.com	Email:		Sampled By:	K. Nero	Rush Confirmation #:

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

Regulation 153: [ ] Table 1 [ ] Res/Park [ ] Med/ Fine [ ] Table 2 [ ] Ind/Comm [ ] Coarse [ ] Table 3 [ ] Agri/ Other [ ] Table ____
FOR RSC (PLEASE CIRCLE) Y / N

Other Regulations: [ ] CCME [ ] Sanitary Sewer Bylaw [ ] MISA [ ] Storm Sewer Bylaw [ ] PWQO Region ____ [ ] Other (Specify) ____ [ ] REG 558 (MIN. 3 DAY TAT REQUIRED)

Include Criteria on Certificate of Analysis: Y / N

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

Analysis Requested: # OF CONTAINERS SUBMITTED; FIELD FILTERED (CIRCLE) Metals / Hg / CrVI; BTEX/ PHC F1; PHCs F2 - F4; VOCs; REG 153 METALS & INORGANICS; REG 153 ICPMS METALS; REG 153 METALS (Hg, Cr VI, ICPMS Metals, HWS - B); Corrosivity Package (pH, Sulphate, Chloride, Resistivity, Conductivity); HOLD- DO NOT ANALYZE

LABORATORY USE ONLY: CUSTODY SEAL Y / N — Present: N, Intact: N; COOLER TEMPERATURES: 8/8/7; COOLING MEDIA PRESENT: Y / (N)

#	SAMPLE IDENTIFICATION	DATE SAMPLED (YYYY/MM/DD)	TIME SAMPLED (HH:MM)	MATRIX	# OF CONTAINERS	FIELD FILTERED	Corrosivity Package	COMMENTS
1	458-3 SS6	2019,01,08	AM	Soil	1	n/a	X	1 x 250 mL jar
2	326-3 SS4	2019/01/15	AM	Soil	1	n/a	X	1 x 250 mL jar
3	331-2 SS5	2019/01/11	AM	Soil	1	n/a	X	1x 250 mL jar
4	331-1 SS4	2019,01,11	AM	Soil	1	n/a	X	1x 250 mL jar
5	458-2 SS5	2019/01/10	AM	Soil	1	n/a	X	1x 25 mL jar
6	326-1 SS3	2019,01,17	AM	Soil	1	n/a	X	1 x 25 mL jar
7	326-2 SS3	2019,01,16	AM	Soil	1	n/a	X	1x 25 mL jar
8								
9								
10								

RELINQUISHED BY: (Signature/Print)	DATE: (YYYY/MM/DD)	TIME: (HH:MM)	RECEIVED BY: (Signature/Print)	DATE: (YYYY/MM/DD)	TIME: (HH:MM)
[signature]	Jan 29, 2019	12:30	[signature] DIPIKA SINGH	2019/01/29	12:40

29-Jan-19 12:40
Ema Gitej
B924885
CA2 ENV-1405

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COC-1004 (03/17) White: Maxxam ~ Yellow: Client

APPENDIX D

Non-Standard Special Provisions and Notice to Contractor

<u>NOTICE TO CONTRACTOR</u> – Subsurface Obstructions

Special Provision

The Contactor is advised of the presence of cobbles encountered within the fill at Culvert Site No. 34-326/C especially in the vicinity of the inlet and the outlet of the existing culvert. The Contactor is advised of the presence of cobbles and boulders encountered within the till deposit above bedrock at Culvert Site No. 34-331/C. The Contractor is advised that the bedrock at Culvert Site No. 34-331/C consists of strong limestone.

The presence of the above-noted near surface conditions and bedrock shall be considered by the Contractor in the selection of appropriate equipment and procedures for various activities, including but not limited to excavation, grading, installation of the foundations and installation of cofferdams/protection systems.

<u>DEWATERING STRUCTURE EXCAVATIONS</u> – Item No.

Non-Standard Special Provision

1.0 SCOPE

As part of the work under this item, the Contractor shall design, supply, and install cofferdams at Culvert Site No. 34-326/C, to construct the replacement culvert or rehabilitation of the existing culvert.

All work as shown on the Contract Drawings.

2.0 REFERENCES – Not Used

3.0 DEFINITIONS

Stamped means drawings or details that have been reviewed and stamped "Conforms With Contract Documents". The stamp shall include the date and signature of the Contractor's Engineer.

Contractor's Engineer means an Engineer licensed to practice in the Province of Ontario who has a minimum of five (5) years of experience in the field of design and/or construction of cofferdams. The Contractor shall retain the Contractor's Engineer to ensure conformance with the contract document.

Cofferdam Design Engineer means an Engineer licensed to practice in the Province of Ontario who has a minimum of five (5) years of experience in the field of design and/or construction of bridges. In addition, the Cofferdam Design Engineer shall have had responsible experience in the design of at least 5 other cofferdams. The Contractor shall retain the Cofferdam Design Engineer to ensure conformance with the contract documents and issue certificate(s) of conformance for the design

4.0 DESIGN AND SUBMISSION REQUIREMENTS

The design of cofferdams shall be in accordance with the Canadian Highway Bridge Design Code CAN/CSA-S6-14.

Submission of Shop Drawings

All shop drawings submissions shall bear the seal and signature of the Cofferdam Design Engineer.

The Contractor shall submit to the Contractor's Engineer shop drawings for review and stamping.

At least two weeks prior to the commencement of cofferdam construction, the Contractor shall submit to the Contract Administrator, for information purposes only, four (4) sets of stamped drawings and calculations of the cofferdam system.

The Contractor shall, at least three (3) weeks prior to the commencement of the cofferdam installation, submit to the Contractor's Engineer for review, four (4) sets of drawings and calculations indicating:

- the cofferdam design;
- the location, type and dimensions of each cofferdam to be used;
- a schematic showing the configuration of all cofferdams;

- the thickness of the tremie plug to ensure stability of the design excavation and cofferdam and the pour sequence of the tremie concrete for which the cofferdam was designed to accommodate unbalanced loading from staged placement and variable heights of the tremie concrete.

The Contractor's Engineer shall review all calculations, construction details, shop drawings and procedures.

All submissions shall bear the seal and signature of the Cofferdam Design Engineer and Contractor's Engineer.

5.0 MATERIALS – Not Used

6.0 EQUIPMENT – Not Used

7.0 CONSTRUCTION

The soils at the site should be expected to contain cobbles in the fill material at Culvert Site No. 34-326/C.

Footing or box culvert construction must be carried out in dry conditions. The excavation shall be kept stable during the work.

The Contractor shall cut the cofferdam at the limits indicated on the Contract Drawings at the completion of the construction of the footings.

8.0 QUALITY ASSURANCE

Certificates of Conformance

The Cofferdam Design Engineer shall inspect the installation of each cofferdam prior to the placing of the tremie concrete in that cofferdam. After the installation of each of the cofferdam has been completed, but before placing the tremie concrete, the Contractor shall submit a Certificate of Conformance for each cofferdam to the Contract Administrator, sealed and signed by the Cofferdam Design Engineer. The Certificates of Conformance shall state that the cofferdam is in place, and has been installed in conformance with the stamped shop drawings and the Contract Drawings.

9.0 MEASUREMENT FOR PAYMENT

Measurement for cofferdams shall be by length in metres of cofferdam installed.

10.0 BASIS OF PAYMENT

Payment at the Contract price for the above tender item shall be full compensation for all labour, Equipment and Materials to carry out the work.

EARTH BORROW – Item No.

Non-Standard Special Provision

Amendment to OPSS.PROV 212, November 2013

212.05.01 Earth Borrow

Subsection 212.05.01 of OPSS.PROV 212 is amended by the addition of the following:

Earth borrow shall have a plasticity index less than 15 per cent and a liquid limit less than 35 per cent.

EXCAVATING AND BACKFILLING STRUCTURES – Item No.

Non-Standard Special Provision

Amendment to OPSS 902, November 2010

902.07.05.02 Excavations for Foundations

Subsection 902.07.05.02 of OPSS 902 is amended by the addition of the following:

The footprint of the area for the box culverts and the area of the strip footings for the open-footing culverts must be proof rolled to identify any soft conditions.

Where any softened zones are present, sub-excavation is required to remove unsuitable materials, and the sub-excavated area must be backfilled with granular material meeting OPSS.PROV 1010 (Aggregates) Granular 'A' or Granular 'B' Type II that is placed and compacted in accordance with OPSS.PROV 501 (Compacting), as amended by SP 105S12.

PROTECTION SYSTEM – Item No.

Special Provision

Amendment to OPSS 539, November 2014

593.07.02 Removal of Protection Systems

Subsection 539.07.02 of OPSS 539 is deleted in its entirety and replaced with the following:

Protection systems shall be removed from the right-of-way unless it is specified in the Contract Documents that the protection system may be left in place.

Where piles are left in place, the top(s) shall be removed to at least 1.2 m below the finished grade or ground level or creek bed or ditch bottom.

The method and sequence of removal shall be such that there shall be no damage to the new work, existing work and facility being protected.

All disturbed areas shall be restored to an equivalent or better condition than existing prior to the commencement of construction.

WORKING SLAB - Item No.

Special Provision

1.0 Scope

This Special Provision covers the requirements for the supply and placement of a concrete working slab under foundations and box culverts where necessary for the culvert replacements at Culvert Site Nos. 34-326/C, 34-331/C and 34-458/C.

2.0 References

This Special Provision refers to the following standards, specifications or publications:

Ontario Provincial Standard Specifications, Construction

OPSS 902 Excavating and Backfilling - Structures

3.0 Definitions - Not Used

4.0 Design and Submission Requirements - Not Used

5.0 Materials

Concrete for working slabs shall have a minimum thickness of 100 mm and a minimum of 28 day compressive strength of 20 MPa.

6.0 EQUIPMENT - Not Used

7.0 CONSTRUCTION

7.01 Excavation

Excavation for the working slab shall be according to OPSS 902.

7.02 Protection of Founding Soil

Following inspection and approval of the prepared subgrade, a working slab with a minimum thickness of 100 mm shall be placed on the foundation subgrade as specified in the Contract Documents.

7.04 Dewatering

Dewatering shall be carried out according to OPSS 902.

8.0 Quality Assurance - Not Used

9.0 Measurement for Payment - Not Used

10.0 Basis of Payment

10.01 Working Slab - Item

Payment at the Contract price for the above tender item shall be full compensation for all labour, Equipment and Material to do the work.

END OF SECTION

<u>VIBRATION MONITORING</u> **– Item No.**

Special Provision

TABLE OF CONTENTS

1.0 SCOPE

This special provision describes requirements for vibration monitoring during excavations and installation of spread/strip footings, box culverts, cofferdams and temporary protection systems for the replacement of the culvert at Culvert Site Nos 34-326/C, 34-331/C ad 34-458/C.

2.0 REFERENCES

The subsurface conditions at the site are described in the following Foundation Investigation Report titled:

> FOUNDATION INVESTIGATION REPORT
> Culvert Replacements, Structure Nos. 34-326/C, 34-331/C and 34-458/C, Highway 3 and 140, City of Port Colbourne and City of Welland, Ontario Ministry of Transportation, Ontario, GWP 2374-15-00

3.0 DEFINITIONS

For the purpose of this specification, the following definitions apply:

Contractor's Engineer means an Engineer with a minimum of five (5) years' experience in the field of installation of piling and vibration monitoring or, alternatively, with expertise demonstrated by providing satisfactory quality verification services for a minimum of two (2) projects of similar scope to the Contract. The Contractor's Engineer shall be retained by the Contractor to ensure general conformance with the Contract Documents and issue certificates of conformance.

Peak Particle Velocity (PPV) means the maximum component velocity in millimetres per second that ground particles move as a result of energy released from vibratory construction operations.

Pre-Construction Condition Survey means a detailed record, accompanied by film or video, as necessary, of the condition of private or public property, prior to the commencement of vibratory construction operations.

Post-Construction Condition Survey means a detailed record, accompanied by film or video, as necessary, of the condition of private or public property, after completion of vibratory construction operations.

4.0 DESIGN AND SUBMISSION REQUIREMENTS

4.1 Submission Requirements

The Contractor/Contractor's Engineer shall submit details of the vibration monitoring plan to the Contract Administrator for information purposes at least 2 weeks prior to any work related to excavation, strip footing, foundation, cofferdam and temporary protection system installation. The submittals shall satisfy the specifications and at a minimum contain the following specific information:

a) Equipment and methods used by the Contractor to perform the work that may cause undue vibration.
b) Qualifications of vibration monitoring specialist.
c) Details regarding proposed instrumentation.
d) Proposed location of instruments adjacent to the on the residences, structures, utilities, wells, or other potentially vibration-sensitive structures within a 250 m radius from the excavation and installation of spread/strip footings, box culverts, cofferdams, and temporary protection systems, as applicable.
e) Proposed frequency of readings.
f) Action plan to be taken to adjust excavation, foundation and protection system installation methods if readings show vibrations exceeding tolerable levels.

6.0 EQUIPMENT

6.1 Vibration Monitoring Equipment

All vibration monitoring equipment shall be capable of measuring and recording ground vibration PPV up to 200 mm/s in the vertical, transverse, and radial directions. The equipment shall have been calibrated within the last 12 months either by the manufacturer or other qualified agent. Proof of calibration shall be submitted to the Contract Administrator prior to commencement of any monitoring operations.

7.0 CONSTRUCTION

7.1 Pre- and Post-Construction Condition Surveys

A Pre-Construction Condition Survey and Post-Construction Condition Survey shall be prepared for all buildings, utilities, structures, water wells, and facilities within 250 m of excavation and installation of spread/strip footings, box culverts, cofferdams, and temporary protection systems.

7.1.1 Pre-Construction Condition Surveys

The standard inspection procedure shall include the provision of an explanatory letter to the owner or occupant and owner with a formal request for permission to carry out an inspection.

The Pre-Construction Condition Survey, at each structure/utility/well/facility within a 250 m radius of the excavation and installation of spread/strip footings, box culverts, cofferdams, and temporary protection systems, shall be completed a minimum of two (2) weeks prior to commencement of excavation and installation of shallow foundations, culverts and temporary protection systems. Only one Pre-Construction Condition Survey per structure or facility is required to be carried out in advance of excavation and installation of spread/strip footings, box culverts, cofferdams, or temporary protection system installation, unless more than six (6) months will elapse between these operations, in which case an interim inspection will be required.

The Pre-Construction Condition Survey shall include, as a minimum, the following information:

a) Type of structure, including type of construction and if possible, the date when built.
b) Identification and description of existing differential settlements, including visible cracks in walls, floors, and ceilings, including a diagram, if applicable, room-by-room. All other apparent structural and cosmetic damage or defects shall also be noted. Defects shall be described, including dimensions, wherever possible.
c) Digital photographs or digital video or both, as necessary, to record areas of significant concern.

Photographs and videos shall be clear and shall accurately represent the condition of the property. Each photograph or video shall be clearly labelled with the location and date taken.

A copy of the Pre-Construction Condition Survey limited to a single residence or property, including copies of any photographs or videos that may form part of the report, shall be provided to the owner of that residence or property, upon request.

7.1.2 Post-Construction Condition Surveys

The standard inspection procedure shall include the provision of an explanatory letter to the owner or occupant and owner with a formal request for permission to carry out an inspection.

A Post-Construction Condition Survey at each structure/utility/well/facility within a 250 m radius of the excavation and installation of spread/strip footings, box culverts, cofferdams, and temporary protection systems, is required within two (2) months of completion of the excavation and installation of shallow foundations, culverts and temporary protection systems.

The Post-Construction Condition Survey shall include, as a minimum, the following information:

a) Identification and description of existing differential settlements, including visible cracks in walls, floors, and ceilings, including a diagram, if applicable, room-by-room. All other apparent structural and cosmetic damage or defects shall also be noted. Defects shall be described, including dimensions, wherever possible.
b) Digital photographs or digital video or both, as necessary, to record areas of significant concern.
c) Comparison between pre-condition survey documented concerns and post-condition concerns.

Photographs and videos shall be clear and shall accurately represent the condition of the property. Each photograph or video shall be clearly labelled with the location and date taken.

A copy of the Post-Construction Condition Survey limited to a single residence or property, including copies of any photographs or videos that may form part of the report, shall be provided to the owner of that residence or property, upon request. The report shall confirm that there have been no changes to the property between the Pre-Construction Condition Survey and the Post-Construction Condition Survey as a result of the excavation and installation of spread/strip footings, culverts and temporary protection systems.

7.2 Monitoring

The vibration monitoring equipment shall be placed on the ground surface in the vicinity of each foundation element or protection system, and on the ground surface at radial distances of 25 m, 50 m, and 100 m from the foundation element or protection system locations within the project. The Contractor shall take readings continuously during excavation and installation of spread/strip footing, box culverts, cofferdams, and during installation of temporary protection systems, and shall immediately notify the Contract Administrator if the vibrations exceed the limits specified herein.

The vibrations measured on private structures, wells, etc. shall not exceed 25 mm/s. Those measured on utilities, if applicable, shall not exceed 10 mm/s.

If the readings are not within the limits stated above, the Contractor must alter the installation procedures until the vibrations at the various locations are within acceptable levels.

7.3 Records

The Contractor/Contractor's Engineer shall submit details of the vibration monitoring to the Contract Administrator as follows:

a) The time/duration of each reading.
b) Construction operations (i.e. installation of sheet piling) and timing of such relative to the readings.
c) Details of exceedances and modifications to operations.
d) Final report containing all relevant data including vibration monitoring and Pre- and Post-Construction Condition Surveys.

10.0 BASIS OF PAYMENT

Payment at the Contract price for the above tender item shall be full compensation for all labour, Equipment and Material required to do the work.

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