Foundation Investigation and Design Report – Highway 401 Improvements from Hespeler Road to Townline Road, Stage 4A, Muskeg/Organic Subgrade

MTO Southwest Region

G.W.P. 3222-15-00
Geocres No. 40P08-299
MTO Contract 2020-3032

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For
G.W.P 3222-15-00

Muskeg Area Between Approximate Stations 10+600 to 10+950,
Near Highway 401 Underpass at Townline Road, City of Cambridge, Ontario

1.0 INTRODUCTION

It is understood that an area of muskeg/organics was encountered within the footprint of the planned embankment widening between approximate Stations 10+600 to 10+950, adjacent to the Highway 401 east bound lanes, east of the underpass at Townline Road in the City of Cambridge, Ontario.

Stantec Consulting Ltd. (Stantec) was retained by the Ministry of Transportation of Ontario (MTO) to undertake a foundation investigation to determine the thickness and extent of muskeg/organics between Stations 10+600 to 10+950.

This report presents the factual data on the subsurface conditions at the site.

2.0 SITE DESCRIPTION, GEOLOGY, BACKGROUND DOCUMENTS

2.1 SITE DESCRIPTION

The site location is shown on the Key Plan inset to Drawing No. 1, provided in Appendix A. At the project site, Highway 401 is oriented in an east-west direction and Townline Road (also known as Waterloo Regional Road 33) is oriented in a north-south direction and crosses above Highway 401, approximately 600 m west of the muskeg investigation area.

At this location, Highway 401 is a six-lane (three lanes in each direction) divided freeway with additional speed change lanes connecting to the Townline Road on-ramp and off-ramp.

The following is a summary of the geometry of the roadway platform between Stations 10+600 to 10+950:

- Elevation of Highway 401 East Bound Lanes: 306.9 m to 307.9 m
- Elevation of South Ditch Line: 305 m
- Approximate Embankment Height: 2 m to 3 m
- Embankment Side Slope: Approximately 3.5H:1V

There are two 1.2 m by 1.2 m Rigid Frame Box culverts at approximate Stations 10+574 and 10+664 discharging water to the area. Puslinch Lake, a kettle lake, is located approximately 400 m± south of the site.

The site is generally sloped away from the highway and a slumped portion of the highway embankment side slope was observed during the investigation. Figure 2.1 shows the extent of slumped portion of the highway embankment as well as ponded water in the low-lying area between the embankment toe and a silt fence installed approximately 16 m± away from the embankment toe.

Peat is visible at the ground surface near the toe of the embankment. Interpreted Google Earth satellite imagery (Figure 2.2) indicates that the peat deposit likely extends to Lake Road (Wellington Road 32) which is located ± 190 m south of Highway 401.

It is understood that construction activities provoked the surface slumping, indicating possible compression of materials beneath the former sideslopes or a lateral slope movement. Figure 2.1 indicates that new fill materials were placed in the area where surface slumping was noted.

Figure 2.1: Slumping of highway embankment slope, visible new fill to the left, visible surface water on peat bog - View of the site looking east

Figure 2.2: Approximate aerial extent of the muskeg deposit between Highway 401 and Lake Road.

2.2 PHYSIOGRAPHIC DESCRIPTION

According to Chapman and Putnam (1984), the site is located within a physiographic region known as the Horsehoe Moraines (mainly, till deposits). Within this physiographic region there also exists outwash gravel deposits and swamp and bog deposits formed in undrained depressions and poorly drained areas. In some areas, mapped kettle bogs were indicated to exceed 6 m in depth.

Based on the Ontario Geological Survey (OGS) surficial and bedrock geology maps, the surficial geology at the site consists either of sandy silt to silty sand glacial tills of the Paris Moraine left behind by the Laurentian glaciation, overlain by outwash gravel deposits and organic deposits (peat, muck, and marl). The bedrock geology at the underpass site consists of sandstone, shale, dolostone, or siltstone of the Guelph Formation.

2.3 REVIEW OF PREVIOUS GEOTECHNICAL INVESTIGATIONS

Reference is made to the letter report prepared by Peto MacCallum Ltd. (PML) titled "*Stage 4A Muskeg/Organics Soils Recommendations, MTO Contract 2022-3032, Hespeler Road Underpass Replacement, Cambridge, Ontario*" dated August 12, 2022. This report summarizes the results of six test pits excavated by Dufferin Construction (Contractor) between Stations 10+700 and 10+900. Five test pits reported depths of organics between 3 m and 4.5 m, and one test pit extended to a depth of approximately 6.5 m was terminated within the organic layer. The organic layer was described in the report as compressible with a high moisture content.

Treatment options suggested in the PML report includes soil reinforcement such as rigid inclusions, incorporation of lightweight materials such as cellular concrete, and a combination of preloading and use of geogrids.

During the May 16, 2023, teleconference call with the Ministry, the Contractor and Stantec, the Contractor noted that movement of the road embankment adjacent to the excavations was observed during the test pit excavations. The Contractor also noted that the muskeg surface was too soft to support tracked equipment without a work pad.

2.4 MTO CONTRACT NO. 2003-3018

MTO Contract No. 2003-3018 include the following Operational Constraint Special Provision.

> "The contractor is advised of a peat bog that extends from approximate Highway 401 Station 10+750 to 10+950, beneath the S-E Ramp speed change lane, and the need to make any adjustments to methods/operations as required (i.e. no end dumping). Any work performed by the Contractor to accommodate such adjustments shall be deemed to be included in the Contract bid price and no additional payment shall be made."

The pavement borehole records show where peat was encountered, from 10+800 to 10+930, with full penetration depths ranging from 4.5 m to 7.2 m. The peat moisture content ranged from 200% to 1013%, but generally over 700% at a depth of over 3.5 m.

Where boreholes were drilled within 9.0 m from the old edge of pavement (EP), no peat was reported; the old EP was 15 m from the median centerline.

Alternating layers of soil fill and peat were reported from about 10 to 12 m from old EP, but not consistently, to depths of about 3.7 m. As an example, at 10+886, at 10.0 m from old EP there is interlaying of peat and fill up to 3.7 m followed by peat, at 11.5 from old EP, there is interlaying up to 0.9 m, followed by peat. This could suggest that as part of the initial construction, full peat removal was only carried out to about 9 m from the old EP or about 24 m from the existing Highway 401 centerline.

Some of the boreholes were drilled from the toe of the slope, at angles of 45 degrees to determine how far the peat extended inward from the toe of the slope. Based on the information from Station 10+886, the peat extended at least 4.2 m inward from the toe of the slope.

The pavement boring record sheets are included in Appendix B. Based on the pavement borehole records, peat was fully penetrated at following locations.

Table 2.1: Summary of Contract 2003-3028 Peat Investigation Information

Location	Depth	Comments
10+800, 13.0 m from EP	4.5 m	No peat at 6.8 m from old EP
10+836, 15 m from EP	7.2 m	No peat at 8.3 m from old EP
10+850, 16.4 m from EP	> 6.0 m	Peat also encountered at 9.9 and 11.4 m from old EP
10+886, 10.0 m from EP	> 5.4	No peat at 8.8 m from old EP At toe of embankment slope Alternating layers of soil and peat at 10.0 m, 10.4 m, 11.5 m
10+886, 13.0 m from EP	5.5 m	
10+900, 13.0 m from EP	5.7 m	No peat at 7.1 m from old EP Peat encountered at 10.7, 14.9, 15.2, 22.5 RT from old EP
10+930, 10.2 m from EP	> 3.3 m	Layers of fill and peat
10+930, 14.9 m from EP	5.2 m	No peat at 8.7 m from old EP Peat encountered at 10.2 m,11.9 m

Based a on review of the construction drawings, from 10+750 to 10+843.8, the overall widening would have transitioned from about 8.25 m at the end of the N-E Ramp gore area to 7 m at 10+843.8.

From10+843.8 to 11+028.3, which covers most of the muskeg area, the platform widening was 7 m, from former EP to the new outside edge of widening, and no peat bog treatment was proposed. The new outside edge of widening in this area would be 22 m the Highway 401 centerline.

Based on the information contained in the Contract 2003-3028 documents and other historical documents, the following is assumed:

- This section of Highway 401was originally open to traffic in 1960. It is understood to have been initially constructed with a grass median which was eventually converted to accommodate a third lane with a barrier wall separating the traffic directions. In 2004, the edge of pavement was 15.0 m from the control line, where the concrete barrier wall is located.
- The contract borehole records suggest that the original peat excavation, at its base, may have extended to about 22 m south of the Highway 401 control line, possibly less in some areas and more where the peat was deeper.
- Based on the above, a core construction approach, extending from a1H:1V outward projection from original edge of pavement, or the 2004 edge of pavement, would have been carried out.
- From 22 m to about 27 m south of the control line, the fill material contained some peat at some locations, suggesting that excavation fill material may have pushed into the peat or general filling was being carried out in this area for general disposal purposes.
- The outside limit of the speed change lane paved shoulder constructed in 2004 extends to 21 m south of the Highway 401 control line.

2.5 ONTARIO HIGHWAY SERVICES RECONSTRUCTION PROJECT

This project included the installation of a 100 mm sanitary forcemain and a 150 mm watermain approximately 42 m and 44 m south of the Highway 401 control line. The services were installed by horizontal directional drilling. The profile drawings include the following approximate borehole information.

Hwy 401 ± 11+950	Peat from el. 305.1 m to 301.0 m (4.1 m)
Hwy 401 ± 10+823	Peat and organic silt from el. 305.0 m to el. 301.0 m (4.0 m)

In these boreholes, the water level was close to el. 304 m.

3.0 INVESTIGATION PROCEDURES

3.1 FIELD INVESTIGATION

A geotechnical investigation was carried out by Stantec between March 23rd and 29th, 2023, and consisted of drilling six boreholes numbered BH23-1 to BH23-6 between Stations 10+600 and 10+900. Two boreholes, BH23-5 and BH23-6, were drilled through the highway shoulder, and the other boreholes were drilled near the embankment toe in the muskeg area. The approximate borehole locations are shown on Drawing No. 1, Appendix A.

Prior to carrying out the field investigation, Stantec contacted the public utility authorities and retained the service of a private utility locator to clear the borehole locations of public utilities. Based on the underground utility locates, a watermain and sewer are aligned parallel to the highway approximately 16 m away from the embankment toe.

Drilling on the highway shoulder was carried out with a Geoprobe 3126 truck mounted drill rig equipped for soil sampling. A Massenza drill rig was used to drill boreholes in the muskeg area at the embankment toe and to collect split spoon samples by manual methods. The boreholes were advanced using continuous flight hollow stem augers. Stantec's staff observed and recorded the drilling, sampling and in situ testing operations, and logged the boreholes.

Split spoon samples were collected at regularly spaced intervals of 0.76 m. Soil sampling was carried out using a 51 mm (outside diameter) split-tube sampler by conducting Standard Penetration Tests (SPTs) in accordance with the procedures outlined in ASTM D1586 Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils.

Shelby tubes were used to collect relatively undisturbed samples of the peat. Each tube was hydraulically pushed into the peat 610 mm (24 inches) with a smooth, continuous thrust and samples were collected in accordance with *ASTM D1587 Thin-Walled Tube Sampling for Geotechnical Purposes*. The samples were used in unit weight and consolidation tests.

Groundwater conditions were also observed in open boreholes during and upon completion of drilling. The boreholes were subsequently backfilled in accordance with Ministry of the Environment Regulation 903.

3.2 LOCATION AND ELEVATION SURVEY

The borehole locations and their respective ground surface elevations were surveyed by Stantec Geomatics personnel using a R12 GPS receiver unit. The survey information and borehole drilling details are summarized in the following table.

Table 3.1: Borehole Information Summary

Borehole No.	MTM Zone 11 Coordinates		Ground surface elevation (m)	Borehole Depth (m)	End of borehole elevation (m)	Number of soil samples
	Northing (m)	Easting (m)				
BH23-1	4811683.14	484880.69	306.1	4.4	301.7	6
BH23-2	4811715.20	484937.44	305.1	6.7	298.4	7
BH23-3	4811752.74	484995.63	305.1	10.5	294.6	13
BH23-4	4811784.45	485048.11	305.3	8.2	297.0	11
BH23-5	4811786.41	485021.64	306.3	11.3	295.0	15
BH23-6	4811817.00	485070.25	306.4	10.5	295.9	14

3.3 LABORATORY TESTING

All recovered soil samples were placed in moisture-proof bags and returned to Stantec's Ottawa laboratory for detailed classification and testing. The recovered soil samples were subjected to visual identification and select soil samples were subjected to a laboratory testing program consisting of natural moisture content, grain size distribution analyses, Atterberg limits determinations, and one-dimensional consolidation testing in accordance with MTO and/or ASTM Standards as appropriate.

Soil samples were also submitted to Paracel Laboratories Ltd. for chemical testing. The laboratory testing program is summarized in the following table.

Table 3.2: Laboratory Testing Program

Test Description		Number of Tests
Geotechnical	Moisture Content	63
	Hydrometer & Sieve Analyses (Grain Size Distribution)	9
	Atterberg Limits	4
	Consolidation	2
	Specific Gravity	1
Chemical Analysis	Organic Content	14
	Corrosivity (pH, resistivity, chloride, and sulphate content)	3
	pH	2

Samples remaining after testing will be placed in storage for a period of one year after issuance of the final report. After the storage period, the samples will be discarded unless we are directed otherwise by MTO.

4.0 SUBSURFACE CONDITIONS

Record of Borehole sheets are presented in Appendix B. Details of the encountered soil stratigraphy are presented in the Record of Borehole sheets, and on the “Borehole Locations and Soil Strata” drawings in Appendix A. An overall description of the stratigraphy is given in the following paragraphs. However, the factual data presented in the Record of Borehole sheets governs any interpretation of the site conditions.

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

In addition to information obtained from the current information, the Soil Strata drawing provided in Appendix A relies on the historic borehole data discussed in Sections 2.4 and 2.5; sources references are included on the drawing.

In general, the subsurface stratigraphy encountered in the boreholes advanced at the muskeg area, BH23-2, BH23-3, and BH23-4, consisted of a deposit of peat overlying deposits of very loose to loose silt to sandy silt, and sandy clay. The aerial limits of the peat based on a visual inspection of the ground surface is shown on Drawing No.1 in Appendix A. At the remaining borehole locations, BH23-1, BH23-2, BH23-6, the subsurface consisted of compact highway embankment fill material, over compact to very loose silty sand to sand fill material, overlying a of very loose to compact sandy silt and sand to silty sand.

4.1 FILL MATERIALS

4.1.1 Shallow Fill Materials

Sand and gravel fill was encountered at ground surface in boreholes BH23-5 and BH23-6 drilled on the highway shoulder. The thickness of the sand and gravel fill is approximately 0.8 m and 2.3 m, and the fill extends to elevations of 305.6 m and 304.1 m. Trace organics was also encountered within the fill in the borehole BH23-6.

Standard Penetration tests carried out in the sand and gravel fill measured SPT N-values of 10 blows to 17 blows for 0.3 m of penetration, indicating a compact relative density. The moisture content of samples of the sand and gravel fill range from 6% to 12%.

Fill material described as sandy organic silt with trace gravel was encountered at ground surface at BH23-1. The fill is 0.8 m thick and extends to elevation 305.4 m. A Standard Penetration Test performed in this fill material measured a SPT N-value of 4 blows for 0.3 m of penetration, indicating a very loose relative density. The moisture content of a sample of the sandy organic silt is 1064%.

4.1.2 Deep Fill Materials Beneath the Highway Adjacent to the Muskeg Area

Beneath the roadway platform, the shallow fill at BH25-05 and BH25-06, drilled in front of the muskeg area, is underlain by a sand to sandy silt fill. The deep fill extended to 8.4 m and 9.1 m below ground surface, corresponding to approximate elevations of 297.9 m and 297.2 m.

Standard Penetration tests performed in the deep fill deposit measured SPT N-values ranging from 0 blow to 5 blows per 0.3 m, with most values consisting of 0 blows, indicating a very loose relative density. A 0 blow value indicates that more than 300 mm of penetration occurred under the initial drop-hammer blow.

The moisture content of samples of this deposit ranges from 9% to 21%.

Grain size distribution tests were carried out on four samples of the silty sand to sand deposit and the results are illustrated on the grain size distribution plots in Figure C1, in Appendix C.

At BH23-06, the results of the grain size distributions tests carried out on three samples of the deep fill material revealed a relatively consistent grain size distributions, as shown below.

- Gravel: 5% to 15%
- Sand: 52% to 54%
- Silt size: 27% to 33%
- Clay size: 4% to 5%

The Unified Soil Classification System (USCS) group symbol for this soil fill is SM (silty sand).

At BH23-05, drilled slightly closer to the shoulder rounding, the deep fill included two interlayers of organic matter and clayey silt, each estimated as 0.5 m thick. A moisture content of 90% was measured in an organic portion. The following grain size distribution was measured on one sample from this borehole.

- Gravel: 1%
- Sand: 36%
- Silt size: 62%
- Clay size: 1%

The sandy silt fill in BH23-05 was found to be non-plastic and the corresponding USCS group symbol to be ML.

4.2 SILTY SAND

West of the muskeg area, in BH23-1, the surface fill material is underlain by a natural silty sand deposit encountered 0.8 m below ground surface. The borehole was terminated within this layer at a depth of 4.4 m, corresponding to a borehole termination elevation of 301.7 m.

Standard Penetration tests performed in the upper silty sand to sand deposit measured SPT N-values that ranged from 2 blow to 14 blows per 0.3 m indicating a very loose to compact relative density; below 1.5 m, the N-values ranged from 11 to 14.

The moisture contents of samples of this deposit range from 12% to 28%.

4.3 PEAT

A black to brown peat deposit was encountered at ground surface in boreholes BH23-2, BH23-3, and BH23-4. The peat deposit was 4.2 m to 7.4 m thick and it extended to elevations ranging from 300.8 m to 297.7 m.

The borehole data indicates that an upper amorphous peat layer overlies fibrous peat; this layer has been interpreted as excavated peat placed over the peat bog as part of the original construction. This upper amorphous peat layer is indicated as a fill material on the Records of Borehole, is approximately 1.5 m thick, and it extends to elevations ranging from 303.8 m to 303.6 m.

The measured SPT N-values in the peat deposit ranged from 0 (sampler penetrated under weight of the hammer) to 2 blows per 0.3 m. Moisture content tests carried out on selected peat samples indicated natural moisture contents in the range of 332% to 1069%.

The recovered peat samples were classified in the lab based on the degree of humification according to ASTM D5715 – 23: Standard Practice for Estimating the Degree of Humification of Peat and Other Organic Soils (Visual/Manual Method). The degree of humification is classified based on a scale of H1 to H10, with H1 being the least decomposed and H10 being the most decomposed. Peats whose degree of humification ranges from H1 to H3 are described as fibrous peat and a humification range of H4 to H10 is used to describe amorphous peat.

Chemical laboratory testing was also carried out on selected peat samples and the laboratory results are included in Appendix C. The degree of humification of encountered peats are shown on the record of boreholes.

The peat is amorphous from ground surface to 1.5 m in boreholes BH23-2, BH23-3, and BH23-4 and is described on the Records of Boreholes as a fill. Below 1.5 m, the peat deposit is described as fibrous to 4.2 m, 3.8 m, 5.3 m in boreholes BH23-2, BH23-3, and BH23-4. At boreholes BH23-3 and BH23-4, the peat is amorphous from 3.6 m to 7.4 m, and from 5.3 m to 6.6 m depths, respectively.

The organic content of the peat varies from 55.3% to 86.5% and the pH ranged from 6.22 to 6.95. The peat is classified as a Slightly Acidic according to *ASTM D4427 – 23 Standard Classification of Peat Samples by Laboratory Testing.*

It is recognized that some disturbance almost always occurs when sampling peat in Shelby tubes. Field sampling as well as sample extrusion for laboratory testing results in sample precompression which has a noticeable effect on compressibility of the natural peat deposit. Notwithstanding the foregoing, one-dimensional consolidation tests were carried out on two Shelby tube samples of the peat. The test results are illustrated on the void ratio versus stress plots presented in Appendix C. The one-dimensional consolidation test results are summarized in the following table.

Table 4.1: One-Dimensional Consolidation Testing Results

Sample ID	BH23-3/ST7	BH23-4/ST8
Sample Depth/Elevation (m)	4.9/300.2	5.6/299.7
Moisture Content (%)	942	859
Initial Void Ratio (e_0)	14.94	13.39
Initial Unit Weight (kN/m^3)	10.3	10.6
Effective Overburden Pressure σ'_{vo}(kPa)	2.5	4.5
Estimated Preconsolidation Pressure σ'_p (kPa)	10	15
Compression Index C_c	7.02	6.76
Recompression Index C_r	2.71	3.74
Coefficient of Consolidation C_v (mm^2/s)	0.034 – 0.215 (average = 0.135)	0.216 – 1.068 (average = 0.589)
Secondary Compression Index $C\alpha$	0.219 (at 5 kPa axial loading)	0.183 (at 5 kPa axial loading) 0.084 (at 15 kPa axial loading) 0.019(at 32 kPa axial loading)

The compression index was estimated using the following empirical equations with water content of peat samples:

$C_c = W_n/100$ Mesri and Ajlouni (2007)

$C_c = 0.0115\ w_n$ Azzouz et al. (1976)

$C_c = 0.0086\ w_n$ Maeguchi et al. (1975)

$C_c = 0.013\ (w_n - 7)$ Kogure and Ohira (1977) - Linear equation

$C_c = 0.00782\ w_n^{1.07}$ Kogure and Ohira (1978) - Power equation

The variation of the estimated compression index of peat with depth using the above-noted equation is shown on the following graph.

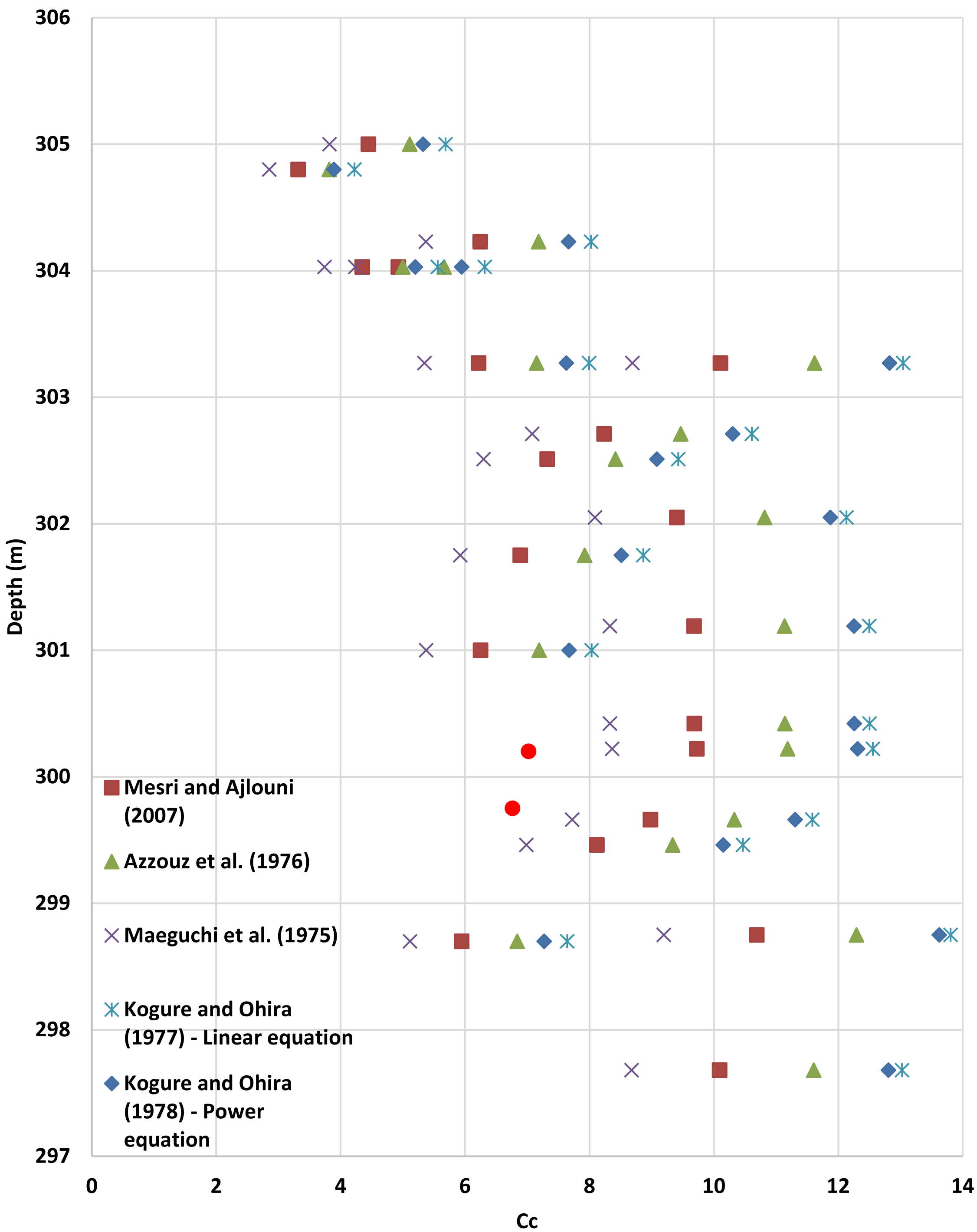

Figure 4.1: The Variation of the Estimated Compression Index of Peat with Depth

Figure 4.1 shows a wide scatter of possible interpretations of the Cc values based on various published correlations; however, these are not inconsistent with the values interpreted from the laboratory tests. A Cc value of 6.0 for the upper portions of the peat and of 7.0 for the lower portions would seem appropriate.

The secondary compression index, $C\alpha$, for the peat has been estimated using the typical correlation suggesting $C\alpha/Cc = 0.06$. The following peat compression parameters have been estimated as typical for the deposit.

	Above el. 302	*Below el. 302*
Moisture content	600%	900%
Cc	6.0	7.0
$C\alpha$	0.36	0.42

4.4 SILT TO SANDY SILT

A native silt to sandy silt deposit was encountered beneath the peat deposit in boreholes BH23-2 and BH23-3, BH23-4. This layer was fully penetrated at BH23-04 at a depth of 7.6 m, at elevation 207.6 m. Boreholes BH23-02 and BH23-03 were terminated within this layer at depths of 10.5 m and 6.7 m, at respective elevations of 298.4 m and 294.6 m.

Standard Penetration Tests carried out in the silt to sandy silt deposit measured SPT N-values that ranged from 0 blows to 6 blows per 0.3 m indicating a very loose to loose relative density.

The moisture content of samples of this deposit ranges from 13% to 36%. In BH23-5/SS7 and BH 23-03/SS10 moisture contents of 90% and 178% were recorded where tested samples had a high organic content.

Grain size distribution tests were carried out on three samples of the silt to sandy silt and the grain size distribution plots are illustrated in Figure C2, in Appendix C. The test results show a grain size distribution consisting of the following.

- Gravel: 0% to 2%
- Sand: 7% to 30%
- Silt size: 60% to 82%
- Clay size: 8% to 11%

Atterberg limits tests were also attempted on four samples of the silt to sandy silt and the test results are plotted on the plasticity chart in Figure C3, in Appendix C. The Atterberg limits test on sample BH23-3/SS11 result in Liquid Limit of 17%, Plastic Limit of 15%, and Plasticity Index of 2%; the Atterberg limits test on the remaining of samples produced a non-plastic result. The USCS group symbol for this deposit is ML (silt/sandy silt).

4.5 LOWER SILTY SAND TO SAND

A silty sand to sand deposit was encountered at 7.6 m, 8.4 m, 9.1 m in boreholes BH23-4, BH23-5, and BH23-6. The boreholes were terminated in this layer after penetrations of 0.8 m, 2.9 m, 2.4 m, at corresponding elevations of 297.0 m, 295.0 m, and 295.6 m.

The measured N-values of Standard Penetration Tests carried out in the lower silty sand to sand deposits ranged from 0 blows to 18 blows per 0.3 m of penetration indicating a very loose to compact relative density. The in-situ moisture content of samples of the lower silty sand to sand deposit range from 12% to 20%.

A grain size distribution test was carried out on a sample of silty sand deposit and the grain size distribution curve is shown in Figure C4, in Appendix C. The test results show the following grain size distribution.

- Gravel: 2%
- Sand: 82%
- Silt size: 14%
- Clay size: 2%

The USCS group symbol for this deposit is SM (silty sand).

4.6 SANDY ORGANIC SILT

Below the peat deposit, a sandy organic silt deposit was encountered in borehole BH23-4 at 6.6 m depth, corresponding to an elevation of 298.7 m. The deposit is 1.0 m thick and extends to 7.6 m depth or elevation 297.6 m. The split spoon sampler was mobilized under the weight of the hammer.

Index tests carried out on one representative sample from the sandy clay layer yielded the following results:

- Gravel: 2%
- Sand: 42%
- Silt: 53%
- Clay: 3%
- Moisture Content: 172%
- Liquid Limits: 158
- Plastic Limits: 46

The USCS group symbol for this layer is OH (sandy organic silt). The results of grain size distribution testing are displayed on Figure C5 in Appendix C.

4.7 GROUNDWATER

The groundwater conditions were observed in the boreholes during and upon completion of drilling. The observed water levels as reported in the Record of Borehole sheets are tabulated below.

Table 4.2: Groundwater Level Observations

Borehole No.	Date	Groundwater Levels	
		Depth (m)	Elevation (m)
BH23-01	March 23, 2023	1.4	304.7
BH23-02	March 24, 2023	0.0	305.1
BH23-03	March 28, 2023	0.0	305.1

As previously mentioned in Section 2, two culverts discharge surface water at the toe of the embankment resulting in ponded water in the low-lying swampland. Based on these observations the groundwater level is at elevation ±305 m.

The groundwater level will be influenced by the free water level in the watercourses and swampland and will also fluctuate seasonally as well as in response to major weather events.

4.8 CHEMICAL ANALYSIS

Chemical analyses related to parameters associated with the potential for corrosion or sulphate attack (i.e., pH, resistivity, and chloride and sulphate content) were completed by Paracel Laboratories Inc. on representative samples of soils collected from the boreholes.

Peat samples were also submitted to Paracel Laboratories Inc. to be tested for pH and organic content. These results can be used to further assess the chemical and organic properties of the peat.

The analytical results are included in Appendix C and are summarized in the following tables.

Table 4.3: Results of Chemical Analysis (Corrosivity)

Borehole No	Sample No.	Depth (m)	Description	pH	Resistivity (Ohm-m)	Chloride (µg/g)	Sulphate (µg/g)
BH23-2	SS7	6.1-6.7	Silt (ML)	7.61	29.9	91	63
BH23-3	SS13	9.9-10.5	Sandy Silt (ML)	7.47	19.7	114	165
BH23-4	SS7	4.6-5.2	Peat (PT)	6.22	7.1	7430	<50

Table 4.4: Results of Chemical Analysis (pH and Organic Content)

Borehole No	Sample No.	Depth (m)	Description	Organic Content	pH
BH23-1	SS2	0.8-1.4	Sandy silt	3.4	N/A
BH23-2	SS1	0-0.6	Peat	74.8	N/A
BH23-2	SS2	0.8-1.4	Peat	N/A	6.94
BH23-2	SS3	1.5-2.1	Peat	75.7	N/A
BH23-3	SS2	0.6-1.2	Peat	61.7	N/A
BH23-3	SS3	1.5-2.1	Peat	N/A	6.95
BH23-3	SS5	3.1-3.7	Peat	73.2	N/A
BH23-3	ST7	4.6-5.2	Peat	81.9	N/A
BH23-3	SS8	5.3-5.9	Peat	82.4	N/A
BH23-3	SS10A	6.9-7.5	Peat	70.2	N/A

Borehole No	Sample No.	Depth (m)	Description	Organic Content	pH
BH23-4	SS2	0.8-1.4	Peat	55.3	N/A
BH23-4	SS4	2.3-2.9	Peat	79.7	N/A
BH23-4	SS6	3.8-4.4	Peat	86.5	N/A
BH23-4	ST8	5.3-5.9	Peat	84.8	N/A
BH23-4	SS9A	6.1-6.7	Peat	70.9	N/A
BH23-5	SS7B	4.6-5.2	Clay with organics	14.7	N/A

5.0 MISCELLANEOUS

- The field work was carried out under the supervision of Wuhib Tamrat, MSc., EIT, and Justin Moleta, EIT, under the direction of Christopher McGrath, P.Eng.
- The private utility locates for the boreholes were carried out by Utility Marx of Hamilton, Ontario.
- The drill rigs were supplied and operated by Strata Soil Sampling of Stouffville, Ontario.
- The location and elevation survey of all the boreholes was carried out by Stantec Geomatics Group based in London, Ontario.
- Traffic control services were provided by Dufferin Construction Company of Oakville, Ontario.
- Chemical testing was out by Paracel Laboratories based in Ottawa.
- Geotechnical laboratory testing was carried out at Stantec's Ottawa laboratory.
- This report was prepared by Ramin Ghassemi, Ph.D., P.Eng., and was reviewed by Raymond Haché, M.Sc., P.Eng., a Principal and Stantec's Designated MTO Contact.

6.0 CLOSURE

A subsurface investigation is a limited sampling of a site. The subsurface conditions given herein are based on information gathered at the specific borehole locations. Should any conditions at the site be encountered which differ from those at the borehole locations, we request that we be notified immediately to assess the additional information.

Respectfully Submitted,

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FOUNDATION DESIGN REPORT
For
G.W.P 3222-15-00

Muskeg Area Between Approximate Stations 10+600 to 10+950,
Near Highway 401 Underpass at Townline Road, City of Cambridge, Ontario

7.0 DISCUSSIONS AND ENGINEERING RECOMMENDATIONS

7.1 PROJECT DESCRIPTION AND BACKGROUND

7.1.1 Project Purpose/Description

This section of the report presents an interpretation of the factual geotechnical data and provides geotechnical design recommendations for embankment widening on the south side of Highway 401 between Station 10+600 and 10+950, in an area where muskeg/organic material has been encountered.

The recommendations are based on:

- Our understanding of the project and our review of background information;
- Field reconnaissance to assess the existing embankment distress, limits of the swampland and likely extent of the deep peat bog;
- Our interpretation of the factual data from the previous subsurface investigations and this investigation; and
- Our analysis of remediation alternatives.

The discussions and recommendations are intended to provide information to enable the design team to assess feasible and practical options for embankment widening that will also meet the performance criteria for allowable settlement as outlined in MTO's *"Embankment Settlement Criteria for Design"*.

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 or operational constraints may be required. Those requiring information on the aspects of construction should make their own interpretation of the factual information provided, as such interpretations may affect equipment selection, proposed construction methods, scheduling and the like.

The existing embankment geometry between Station 10+600 and 10+950 is summarized below.

- Crest of Embankment (Highway 401 East Bound Lanes) Elevation: 306.9 m to 307.9 m;
- Toe of Embankment Elevation: 305 m;
- Embankment Height: 2 m± to 3 m±; and
- Embankment Side Slope: Approximately 3.5 Horizontal :1 Vertical (3.5H:1V).

Highway 401 will be widened to accommodate an additional lane and consequently the existing embankment will require widening. The cross-section geometry of the proposed embankment widening at Station 10+750 is illustrated below. Based on this cross section, embankment widening will require placing up to 1 m of new fill on the existing embankment side slope.

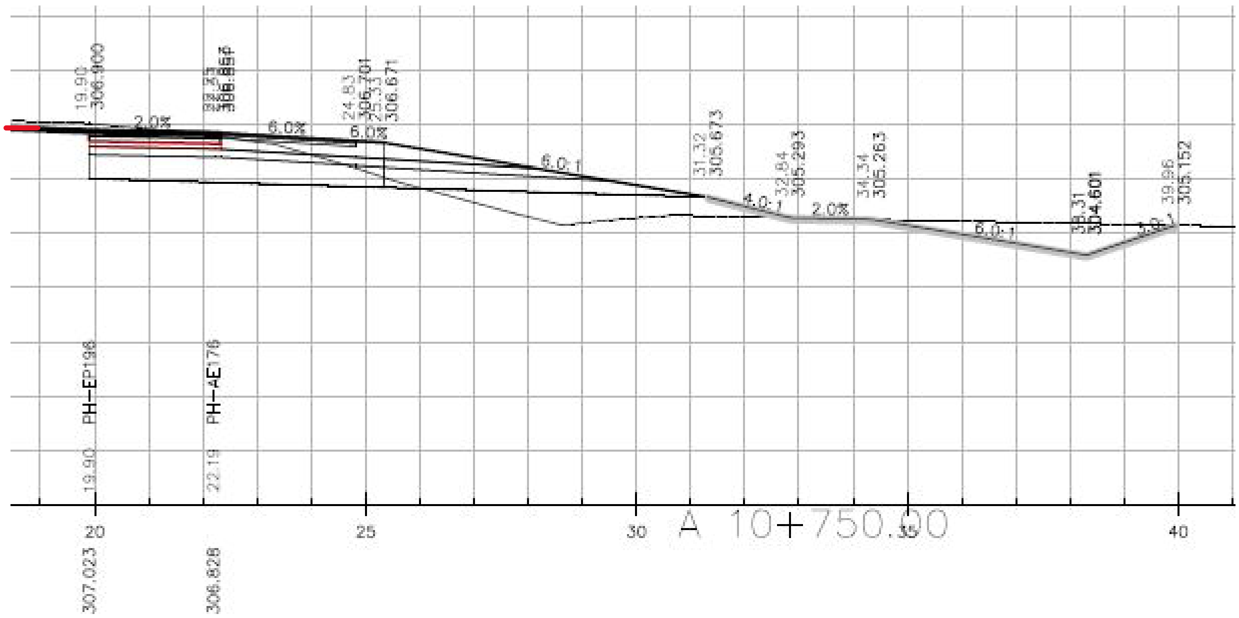

Figure 7.1: Proposed Embankment Cross-Section at Station 10+750

7.1.2 Degree of Site Understanding and Consequence Classification

The Canadian Highway Bridge Design Code (CHBDC S6-19) requires an assessment of the “degree of site and prediction model understanding” as a component of the geotechnical engineering investigation and/or services. The site and prediction model understanding considers the geotechnical properties of the soils underlying the site and the accuracy and degree of confidence regarding the numerical performance prediction models to be used to estimate the geotechnical serviceability limit states reactions and ultimate limit states resistances.

Based on the scope of subsurface investigations completed and available subsurface information related to this site, a “Typical Understanding” has been adopted for foundation design assessment purposes.

The consequence classification has been assumed as “Typical Consequence” in accordance with Section 6.5 of the Commentary on CHBDC S6-19. Should the consequence classification change, the foundation assessment and recommendations provided below should be reviewed and revised accordingly.

7.2 REMEDIATION OPTIONS

7.2.1 Geometric Constraint

Based on the available information, as part of the original highway construction all peat appears to have removed below the original embankment using a core construction approach; all peat within a 1H:1V projection from the original edge of pavement would have been removed and replaced with silty sand which appears to have dumped in place with no compaction, up to the water level. The available borehole information, including that obtained as part of the current investigation, suggest that the base of the peat excavation would have extended laterally to about 22 m from the highway control line, whereas the current shoulder rounding is about 21 m south of the control line.

The existing embankment side slope are underlain by intermixed layers of silty sand materials and peat materials. This interpretation is supported by Figure 2.1, which shows the slumped surface interpreted to be a response to fill placement on the existing embankment side slope, and the information gleaned from the Contract 2003-3028 documents.

Where new embankment loads are placed on the exiting shoulders, significant settlement should be anticipated. Beyond the initial core construction treatment area, the peat is 5 m to 7 m thick throughout most of the peat bog width.

7.2.2 General Treatment Approaches

Settlement related performance issues are expected in the area where new embankment loads are applied from beyond the existing shoulder rounding to the future toe of slope. The following general approaches are typically considered for roadway construction projects.

- Removing the peat by excavation or displacement methods, ultimately replacing the peat with a more competent soil or a rockfill;
- Preloading and surcharging the peat to increase its strength and reduce its compressibility;
- Reducing the embankment loads by using light weight fill materials; and,
- Ground improvement methods to transfer the loads to more competent soils.

Table F-1, presented in Appendix F, provides a broad list of the specific treatment methods commonly used for peat treatment, with some comments to its applicability to this project.

The following options from Table F-1 were initially carried forward as possible treatment methods:

- Ground Improvement methods including deep soil mixing, controlled modulus columns, rigid inclusions, and deformable inclusions.
- Preloading and surcharging
- Full Depth Peat Excavation

The use of light weight fill is excluded for the following reasons.

- Light weight fill materials such as cellular concrete and expanded polystyrene have a lower unit weight than water and cannot be used as a general treatment approach in a peat bog area, where the groundwater level is at ground surface.
- Light weight fill materials can be incorporate in preloading and surcharging designs, provided they are placed above anticipated high-water levels, and if included are considered to be a component to the preloading and surcharge option.

7.3 GEOTECHNICAL DESIGN PARAMETERS

In general, the subsurface stratigraphy encountered in the boreholes advanced at the muskeg area (BH23-2, BH23-3, and BH23-4) consisted of a deposit of peat overlying deposits of very loose to loose silt to sandy silt; the objective of the investigation was limited to defining the extend of the peat deposit and did not include finding an underlying dense or hard soil stratum. The aerial limits of the peat based on a visual inspection of the site is shown on Drawing No.1 in Appendix A.

Adjacent to the peat bog, boreholes BH23-5 and BH23-6 revealed the presence of a compact highway embankment fill material, overlying a deep silty sand fill which appears to have been placed without compaction up to a level consistent with the top of the peat bog. The silty sand fill is generally in a very loose state, with a base level consistent with the adjacent bottom of peat bog level and is underlain by a generally loose sandy silt and sand layers.

A geotechnical model (soil profiles) has been prepared for the design and settlement evaluation. The soil profile is summarized on the following tables. The geotechnical parameters identified in the soil profiles were developed based on a synthesis of the borehole data, the measured penetration resistance values, and laboratory test results (including index test results and consolidation tests) of soil samples obtained in the investigation. The elevations provided on the table reflect a synthesis of the borehole data; reference should be made to the Record of Borehole sheets for the range of conditions encountered.

Table 7.1: Geotechnical Model (non-peat material)

Elevation (m)		Soil Type	Design Soil Parameters		
From	To		Total Unit Weight[2] γ (kN/m^3)	Drained Friction Angle ϕ' (°)	Soil Modulus E(MPa)
306.4 (Ground Surface)	304.9	FILL: SAND & gravel (compact)	22	31	25
304.9	303.5	FILL: UPPER SILTY SAND TO SAND (very loose to loose)	19	29	8
303.5	297.7	FILL: SANDY SILT to SILT (very loose)	18	25	2.5
297.7	295.0	LOWER SILTY SAND TO SAND (very loose to compact)	19	30	10

Notes:

1 Groundwater level at elevation of 305.1 m is recommended to be uses in design

2 Submerged unit weight (γ') should be used below the groundwater level.

Table 7.2: Geotechnical Model – Peat Strength Parameters

Elevation (m)		Design Parameters			
From	To	Total Unit Weight[2] γ (kN/m^3)	Drained Friction Angle ϕ'^3 (°)	Undrained Shear Strength $S_u{}^3$ (kPa)	Preconsolidation Stress (P'$_c$) (kPa)
305.1 (Ground Surface)	301 to 298 (varies)	10.5	36	8	10-15

Notes:

1 Groundwater level at ground surface (elevation of 305.1 m) is recommended to be uses in design

2 Submerged unit weight (γ') should be used below the groundwater level.

3 The friction angles are applicable to drained conditions only and the shear strengths are applicable to undrained conditions only

Table 7.3: Geotechnical Model – Peat Compression Parameters

Elevation (m)		Design Parameters			
From	To	Initial Void Ratio (e_0)	Compression Index (C_c)	Secondary Compression Ratio (C_α/C_c)	Initial Moisture Content (%)
305.1	302	11.0	6.0	0.06	600
302	298	16.2	7.0	0.06	900

7.4 SEISMIC CONDITIONS

7.4.1 Site Class

Based on the very loose nature of the deep fill materials encountered beneath the highway platform, a site Class E would apply to the project. However, based on the subsurface conditions encountered in the boreholes and the presence of a more than 3 m thick peat deposit, this site is assessed to be Seismic Site Class F as per CHBDC S6-19 Commentary Table 4.1. Generally, a site-specific evaluation would be required to determine the seismic site response, however, as discussed below in Section 7.4.2, due to the low level of seismicity at the site, a detail seismic analysis is not warranted.

7.4.2 Peak Ground Acceleration (PGA)

The Canadian Highway Bridge Design code CSA S6-14, currently applicable to the project, does not provide guidance on selecting earthquake return periods applicable to highway embankments away from bridge structures. For this reason, the following discussion is based on the guidance provide in CSA S6-19.

Based on Section 6.14.2.3 of CSA S6-19, for geotechnical systems falling within seismic performance Categories 2 and 3, the following is interpretated to apply to this project.

- Lifeline geotechnical systems shall have at least 50% of the travelled lanes, but not less than one, available for use following ground motions with a return period of at least 975 years.

Seismic hazard values for this site were obtained from Natural Resources Canada (2015 National Building Code). The 2015 NBC Seismic Hazard calculation sheet for this site is provided in Appendix D. Table 7.4 summarizes the applicable NBCC 2015 parameters.

Table 7.4: Peak Ground Acceleration Data

Return Period	PGA	$S_a(0.2)$	$S_a(1.0)$	Site Class	$Site\ Adjusted\ PGA$
2475 years	0.087 g	0.141	0.047	E	0.1575 g
975 years	0.050 g	0.084 g	0.030	E	0.0905 g
475 years	0.030 g	0.052 g	0.020	E	0.0543 g

Based on $S_a(0.2)$ and $S_a(1.0)$ values for the 2475 return period and the definition of the seismic performance categories provided in Table 4.10 of CSA S6-19, the site would correspond to a seismic performance Category 1. For sites with a seismic performance Category 1, the geotechnical system does not need to consider the impact of seismic events.

7.5 EMBANKMENTS

A 4.2 m to 7.4 m peat deposit was encountered at three borehole locations. Construction of road embankments or other infrastructure on soft peat is a challenge. Significant properties of peat are the high compressibility, very high values of $C\alpha$ and Cc, and low undrained shear strength, which could result in large settlement and embankment instability in the case of the proposed highway widening.

The following sections provide guidance on potential soil improvement options, embankment settlement, embankment slope stability, and stability of the stabilized soil mass.

7.5.1 Screening of Treatment Method Options

Generally, the common solutions in dealing with peat areas could be categorized into three broad groups which are provided in Table F-1 in Appendix F. These categories a as follows:

A: Mass Removal of the Peat

- Excavation and replacement
- Peat displacement (mud wave approach)

B: Soil Improvement Methods

- Preloading and surcharging
- Reinforcement
- Load modification – lightweight fill or lowering the profile
- Deep soil mixing (mass mixing, column mixing, or a combination)

C: Load Transfer to the Underlying Soils

- Controlled Modulus Columns or other rigid or semi-rigid inclusions
- Non-rigid inclusions

As noted in the feasibility column in Table F-1, the following options were retained as technically feasible.

- Excavation and replacement
- Preloading and surcharging
- Deep soil mixing

It is noted that the use of controlled modulus columns (CMCs) was considered as non-feasible as a stand-alone solution, however, to improve the long-term performance of the highway, consideration could be given to incorporating CMCs after completion of a preloading and surcharging program by excavating to within 300 mm of the peat bog level, installing the CMCs, then constructing the load transfer platform.

Table F-1 does not include a ranking of the possible options since the key factors (traffic disturbance, schedule impact, and cost) are not geotechnical constraints and their relative importance to the project are beyond the scope of a geotechnical assessment. Table 7.5 provides preliminary opinion of non-geotechnical constraints associated with these treatment methods.

Table 7.5: Preliminary comparison of non-geotechnical constraints

Retained options	Traffic Disruption	Schedule	Cost
Excavation and Replacement	Highest		Highest
Preloading (not including CMCs)	Lowest	Highest	Lowest
Deep Soil Mixing		Lowest	

7.5.2 Excavation and Replacement

The existing embankment shoulder is underlain by intermixed layers of fill and peat, as in some areas directly by peat. The excavation and replacement option should include removal of all materials beyond the current rounding between the shoulder and the embankment slope.

Excavation to remove the peat deposit would require the installation of soil support system for the temporary protection of the highway embankment. Generally, the following would be anticipated.

- Treatment area of about 300 m by 12 m.
- Two rows of parallel sheet piles, one row through the shoulder rounding, and a second row 12 m beyond, both extending several metres beyond the bottom of the peat.
- Construction of a temporary access road into the peat to allow for installation of the outer row sheet pile, likely a combination of geotextiles, geogrids, and up to 2 m of granular fill to allow for a final grade of over 0.5 m above the peat bog.
- Whalers and lateral struts spanning between the sheet piles to provide lateral stability during peat excavation and after backfilling.
- Excavation and backfilling in limited lengths, possibly requiring perpendicular sheet piles to form excavation cells. Excavating the full length would not be possible, even with strut bracing, since the passive resistance of the peat, outside of the sheet-pile row would not be suitable to resist the active pressures from the highway embankment beyond the shoulder rounding.
- As an alternative to excavating in limited sections, the use of tie-back soil anchors could be incorporated into the design.

This option is technically feasible, however the level of effort and the cost of the sheet piling work likely renders this option non-competitive compared to the options discussed further below.

7.5.3 Preloading and Surcharging

For most geotechnical materials such as silts, sands and gravels, compression of the material is almost entirely from primary consolidation, which occurs over a short duration. For organic materials such as peat secondary compression is a significant concern; the associated settlement can be large and occur over a long duration, years to decades.

7.5.3.1 Review Based on MTQ Peat Design and Construction Guidelines

In 2012, Ministry of Transportation of Quebec (MTQ) produced a guide for construction of fills on peat bogs based on their on-site monitoring records and technical documents produced by Samson (1985) and Mesri et al. (1997). Based on a review of the MTQ document, the following is noted.

1. The settlements anticipated in a peat bog is typically expressed as a function of the depth of the peat bog and the final design grade, based on the following equation.

   $$Rt = Hr \cdot 100/(100-T)$$

   Where: Hr is the final height of fill above the peat bog

   Rt is the total thickness of fill required to achieve Hr

   T is the % settlement anticipated, based on the peat thickness

   For a 7 m peat bog thickness, the T factor is 60%. For Hr values of 2.5 m, 2.0 m, 1.5 m and 1.0 m, total fill thicknesses of 6.25 m, 5 m, 3.75 m, and 2.5 m would be anticipated, corresponding total peat compression values of 3.75 m, 3.0 m, 2.25 m, and 1.5 m.

   For a 5 m peat bog thickness, the T factor is 50%. For Hr values of 2.5 m, 2.0 m, 1.5 m and 1.0 m, the total fill thickness required would be 5 m, 4 m, 3 m, and 2 m, corresponding to total peat compression values of 2.5 m, 2 m, 1.5 m, and 1 m.

2. Significant surcharge height is required to eliminated long term settlement. Samson (1985) noted that with a surcharge height equal to 50% of the new fill weight to be left in place, after 5 to 8 years, the rate of secondary settlements progressed as if no surcharge had been placed. Mesri (1997) noted that a surcharge height equal to 100% of the new fill weight to be left in place was required to keep the secondary settlements small for period of 30 years. For a final grade raise of about 1.5 m at the future rounding, where the peat is 7 m thick this would suggest a surcharge height of about 2 m to achieve the 50% target.

3. Notwithstanding the above comments, when crossing a peatbog, the MTQ generally limits the surcharge height to 600 mm, except where there the peat thickness varies over short distances an increase height of 1.2 m is used. The approach limits long-term differential settlements but accepts that long-term total settlements will occur. In the case of the Highway 401 expansion project, where the existing lanes are supported by a silty sand core, this approach would produce differential settlements over the cross-section which should not be considered acceptable; a more aggressive surcharging program would be required.

4. Generally, 80% of the peat compression or settlement occurs during construction and the remaining 20% is considered long-term secondary consolidation.

5. Stability analysis should form part of the preload and surcharge design where the peat's degree of decomposition corresponds to humidification levels of H5 to H10. At the Highway 401 site, the

deeper portions of the peat were assigned humidification levels of H7 to H8, and the amorphous peat fill near the surface, H6.

7.5.3.2 Settlement Estimates based on Laboratory Testing

The MTO Guideline for Foundation Engineering Services dated April 2022 provides embankment criteria for design. The guideline specifies a total settlement of 50 mm (post-construction) and a differential settlement rate of 200:1 for embankment widening on freeways.

A settlement analysis was carried out for the most critical embankment cross section (10+725) to estimate the magnitude of settlements across the embankment widening area. The soil parameters provided in Tables 7.2 and 7.3 were used in the analyses. The following sections summarize embankment settlement estimates for two embankment design options:

Option 1: No preloading or surcharge (do nothing option)

Option 2: Surcharging and preloading with 1.5 m to 2.5 m of fill

Table 7.6: Calculated Settlements beneath the future shoulder rounding

	Lab Results Primary	MTQ Primary	Lab Results Secondary	MTQ Secondary	Comment
Option 1	1850 mm	1800 mm	575 mm	450 mm	Not Feasible
Option 2 1.0 m Surcharge	2580 mm	3000 mm	0 mm up to 4 yrs 250 mm up to 30 yrs	-	Not Feasible
Option 2 1.5 m Surcharge	2850 mm	3600 mm	0 mm up to 30 yrs 40 mm up to 50 yrs	-	Feasible

The estimates provide in Table 7.6 include those based on conventional consolidation theory and the graphical method included in the MTQ guideline document for validation purposes. The two calculation methods are in general agreement.

The above table assumes at total final grade raise at the shoulder rounding of 1.5 m. The calculated settlements indicates that a preloading approach should consider at least 1.5 of surcharge fill to avoid triggering a future settlement.

For preliminary considerations, the following would be anticipated as part of the construction of a surcharge fil on the peat bog.

- Due the presence of amorphous peat at the surface, a separation geotextile and geogrid strengthening would be required as part of the initial base layer where peat is currently exposed.
- Fill placement would need to be carried in lifts likely ranging from 300 mm to 500 mm to avoid triggering slope failures during construction. For a 1.5 m surcharge, inducing 3 m of peat compression, a total fill height of at least 6 m would be required in areas completely underlain by 7 m of peat. This indicates that 12 to 20 lifts would need to be staged.

- For 300 m lifts, a holding period for each stage of one week would be anticipated, suggesting construction of the fill and surcharge could last 20 weeks. The staging period would be monitored using vibrating wire piezometers.
- Once the final grade is achieved, the fill should be kept in place for a period of 120 days. This suggest that a total construction period of 40 weeks should be anticipated.

7.5.4 Deep stabilization (deep soil mixing)

Mass stabilization (deep stabilization or deep soil mixing) is a ground improvement method, where hardened soil mass is created by adding binder into soil and by controlled in situ mixing. Mass stabilization poses an alternative solution for conventional mass replacement or other techniques. Mass stabilization could be carried out in three forms:

- **Full depth mass stabilization –** All of the peat is improved to reduce its compressibility (reduce the settlement) and increase its shear strength.

- **Partial mass stabilization to a given design depth** – Compressible soil layers are left under the stabilized zone. In this case, some settlements will occur, yet the load induced by the embankment is distributed via mass stabilized layer to the lower layers, thus evening out the settlements and reducing differential settlements. Settlements may be still significant, if the applied stresses exceed the pre-consolidation stress of the untreated portion of the peat deposit.

- **Combination of mass and column stabilization –** Column stabilization carried out under mass stabilization reduces the settlements of the untreated portion of the peat deposit underneath mass stabilization. Additionally, this method improves the stability of the embankment by impeding the formation of a slip surface. Most commonly, the combination of mass and column stabilization is used in cases when peat constitutes the uppermost soil layer, because the column stabilization method alone would not provide sufficiently strong columns for the upper part. Mass stabilization can also be used to create a working platform for stabilization machinery in the areas with particularly weak subgrade conditions.

Generally, equipment allows the execution of stabilization to depths of 7 to 8 m under favorable conditions. The optimal stabilization depth is typically in the range of approximately 3 to 5 m (Juha et. al., 2018). These upper limit and optimal depths are for mass soil mixing (i.e., mixing soil by moving the mixing tool through the treatment zone using a track hoe arm and mixing the soil with the slurry, which is injected through a port near the mixing tool). Deeper mass soil mixing could be achieved by deep soil mixing in overlapping columns. During column mixing, the mixing tool mixes the soil as it advances to the maximum treatment depth and continues mixing during withdrawal. Mass soil mixing and deep (column) soil mixing are both possible below the groundwater level.

Mass stabilization is carried out by using either the dry technique, i.e. addition of dry binder or binder mixture or wet (slurry) mixing technique, in which the binder is premixed with water before pumping and mixing with the soil layer. It is noted that the “wet method” demands significantly higher binder addition rate. The dry mixing process also adds some air to the soil via the use of compressed air injected into the mass. The dry technique is the preferred method for peat.

The peat layer is generally mixed to "pre-homogenize" the layer prior to injection of the binder. This process is intended to create a uniform pre-stabilization soil mass with a predictable and consistent result. A pressure feeder injects the binding agent through the hose of the mixing tool. The rotating drums mix the binding agent into the ground and homogenize simultaneously the mixed mass. Mixing is executed by moving the mixer unit vertically and laterally from the surface to the desired depth. The reach of an excavator determines the progress of stabilization work. The work area is generally divided into blocks, or areas, of equal size depending on the site geometry. Typically, the size of a block is between 3 m^2 and 5 m^2 and the work proceeds from block to block.

To account for and counteract the natural loosening of the soil mass produced by mixing and air injection, a preloading embankment of 0.5 m to 1 m height is constructed above the stabilized soil to promote hardening. The preloading embankment can be raised in stages after some hardening has happened to achieve a target final design level. However, regardless of site leveling objectives, the preloading embankment helps the consolidation of the stabilized material during the hardening process (curing of cement). The target strength of the mass stabilization is typically achieved in a period of 1 to 3 months.

It is necessary to carry out QA tests (such as field vane shear tests and Cone Penetration Testing (CPT)) to ensure that the treated peat achieved the target shear strength and compressibility.

For the deep soil mixing option, the settlement analysis assumed that the entire thickness of peat beneath the footprint of the new fill is improved. The analysis assumed an E_{s50} (Secant value of Young's modulus of elasticity at 50 percent of the unconfined compressive strength) of 15 MPa or higher for the stabilized peat mass; the selected value is representative of a stabilized soil mass with an unconfined compressive strength of 300 kPa. The settlement analysis estimated the peat subgrade will settle less than 25 mm (primary consolidation + secondary compression) under new embankment loading.

This option meets the MTO embankment settlement criteria for total settlement and differential settlement.

7.5.5 Embankment Stability

The following comments/assumptions were made on the proposed embankment widening:

- It is assumed that all embankment widening will be done using compacted OPSS 1010 Granular A or B Type II (which has an internal friction angle of 35 degrees or greater after placement) and embankment widening will be carried out in accordance with relevant MTO standards such as OPSS.PROV 206 (subgrade preparation embankment construction) and OPSS.PROV 501 (compaction, quality control).
- In areas where new fill is abutting to the existing embankment fill, the existing fill surface should be properly benched in accordance with OPSD 208.01.
- To reduce surface water erosion on the granular embankment side slopes, topsoil and seeding as per OPSS.MUNI 802 (Topsoil) and OPSS.PROV 804 (Seed and Cover) should be carried out as soon as possible after widening of the embankments.

For reference, selected Highway embankment cross sections are included in Appendix E.

Slope stability analyses were carried out for Section 10+725 of the highway embankment using the commercially available slope stability analysis software, SLOPE/W (GeoStudio 2021 R2). The input geotechnical design parameters are based on the geotechnical model presented in Section 7.2. The short-term analyses included allowance for dynamic loading due to traffic by considering a static surcharge load of 18 kPa (as specified in CHBDC Clause 3.8.3.1.2 CL-W lane load).

The analyses considered five different embankment design configurations, which are summarized below:

1. **Preload and Surcharge**
2. **Deep Soil Mixing – full depth mass mixing**

A minimum factor of safety (FOS) of 1.5 (corresponding to a resistance factor 0.65) is considered acceptable against static conditions.

The results of a slope stability analysis are presented on Figures D1 to D4 in Appendix D and slope are summarized in Table 7.7 below.

Table 7.7: Summary of Slope Stability Analyses (Static Conditions)

Analysis	Soil improvement measure	Figure #	Factor of Safety	Comment
Short-Term (undrained)	**Preload and Surcharge** (1.5 m final surcharge height, from shoulder rounding to future ditch)	D1	1.56	**FoS Acceptable**
	Deep Soil Mixing (Mass soil mixing from shoulder rounding to 12 m beyond shoulder rounding, to el. 297.7 m)	D2	1.50	**FoS Acceptable**
Long-term (drained)	**Preload and Surcharge** (1.5 m surcharge height, from shoulder rounding to future ditch)	D3	1.54	**FoS Acceptable**
	Deep Soil Mixing (Mass soil mixing from shoulder rounding to 12 m beyond shoulder rounding, to el. 297.7m)	D4	1.57	**FoS Acceptable**

Notes:

1 New embankment is assumed to be construct of compacted Granular A or B Type II with friction angle of 35° and unit weight of 22 kN/m^3.

2 Granular mat assumed to be construct of compacted Granular A or B Type II with friction angle of 35° and unit weight of 22 kN/m^3.

3 For undrained analysis, an undrained shear strength of 150 kPa was assumed for the portion of peat mass stabilized by soil mixing. The combined unit weight of the stabilized peat was assumed (conservatively) 12.5 kN/m^3.

4 For drained analysis, a combined apparent cohesion (C') of 20 kPa and an effective friction angle of 36° was assumed for the portion of peat mass stabilized by soil mixing.

Laboratory mix design study, bench testing, and field-mixed specimen testing should be carried out to confirm that the stabilized peat mass will have an unfactored undrained shear strength of 150 kPa and an unfactored apparent cohesion of 20 kPa.

Additional Stability Considerations for Deep Soil Mixing

The deep soil mixing design will need to be carried by a specialist contractor and will need to consider the following.

- The soil mixing should be designed to prevent combined overturning and bearing capacity failure of the stabilized soil mass.
- The geotechnical considerations discussed in this report is based on full depth mass soil mixing, over a length of approximately 300 m, for a lateral distance of approximately 12 m, extending to beyond the bottom of the peat layer. The bottom of the peat layer typically ranges from el. 298 m to el. 300 m along the length of the section to be treated.
- The resultant load eccentricity of less than third of width of deep mixed zone, which is consider acceptable, ie. the resultant should be within the middle third of the width of the treated block.

7.5.6 Recommended Treatment

It is understood that minimizing the construction schedule is the primary objective to be considered in selecting the preferred treatment method. On this basis, the mass soil mixing approach is recommended.

If the construction schedule is later deemed to be more flexible, the preloading and surcharge approach could be further considered.

The mass excavation and replacement alternative is likely excessively expensive given the sheet piling efforts that will be required, and therefore is not recommended.

7.6 CONTRACT SPECIAL PROVISIONS

A non-standard special provision (NSSP) will be required for the stabilization of the peat by means of soil improvement such as deep soil mixing. The NSSP should include the following requirements:

- The stabilized soil mass shall extend laterally from the embankment toe a minimum distance of 2 x the thickness of the peat layer and should extend the full depth of the peat layer.
- The stabilized soil mass and cement mix ratio shall be designed for an Unconfined Compressive Strength of 300 kPa or greater.
- Carry out a trial test laboratory mix design study, bench testing, and field-mixed specimen testing to determine the cement mix ratio and unconfined compressive strength for the site. The test samples should achieve an Unconfined Compressive Strength of 300 kPa or greater after a 28-day curing period.
- Excavation Plan submittal, which includes considerations for site access of equipment, working pads for equipment, dewatering of temporary excavations and temporary embankment slope stability.

- Geotechnical Instrumentation and Monitoring Plan submittal, which includes a series of surface monitoring points installed on the outside through-lane and the speed change lane, plus in-ground monitoring points within the gravel shoulder.
- Deep soil mixing plan submittal, which includes a description of sequence of construction, construction procedures, mix deign(s), injection and mixing parameters, and working drawings.
- Field validation program plan submittal, which outlines the Quality Control/ Quality Assurance testing procedures and frequency.
- As-built drawing and field records documenting the construction process.

7.7 CEMENT TYPE AND CORROSION POTENTIAL

Three soil samples were submitted to Paracel Laboratories Ltd. in Ottawa, Ontario for analysis of pH, water soluble sulphate and chloride concentrations, and resistivity. The testing was completed to determine the potential for degradation of the concrete in the presence of soluble sulphates and the potential for corrosion of exposed steel used in foundations and buried infrastructure. The results of the analysis are summarized in Tables 4.3 and 4.4 in a preceding section of this report.

The concentration of soluble sulphates provides an indication of the degree of sulphate attack that is expected for concrete in contact with soil and groundwater. The soluble sulphate concentrations for the samples tested is between 165 and less than 50 µg/g. Soluble sulphate concentrations less than 1000 µg/g generally indicate that a low degree of sulphate attack is expected for concrete in contact with soil and groundwater. Therefore, based on the soil testing results, Type GU (General Use) Portland Cement should therefore be suitable for use in buried concrete.

The pH, resistivity, and chloride concentration provide an indication of the degree of corrosiveness of the sub-surface environment. The soil samples pH values were between 6.62 and 7.47. The normal range for soil pH is between 5.5 to 9.0.

A comparison of the resistivity test results to literature references indicate a highly to extremely corrosive environment at the site. Additionally, the concentration of chlorides for the tested peat sample (7430 ppm) is indicative of a corrosive environment for steel (Chloride concentration of more than 500 ppm).

8.0 REFERENCES

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Terzaghi, K., Peck, R.B. and Mesri, G. (1996). *Soil Mechanics in Engineering Practice*. 3rd Edition, John Wiley and Sons, Inc., New York.

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9.0 CLOSURE

The recommendations made in this report were made based on our current understanding of the project. Stantec should be given the opportunity to review, and if necessary, revise, the recommendations contained herein when the drawings and specifications are complete.

A soil investigation is a limited sampling of a site. The conclusions given herein are based on information gathered at the specific borehole locations. Should any conditions at the site be encountered which differ from those at the borehole locations, Stantec should be notified immediately in order to assess the additional information and its effects on the above recommendations.

We trust the information presented herein meets your present requirements. Should you have any questions or require additional information, please do not hesitate to contact us.

Respectfully submitted,

STANTEC CONSULTING LTD.

Ramin Ghassemi, Ph.D., P.Eng.
Geotechnical Engineer

Raymond Haché, M.Sc., P.Eng.
Designated Principal MTO Foundation Contact

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APPENDIX A

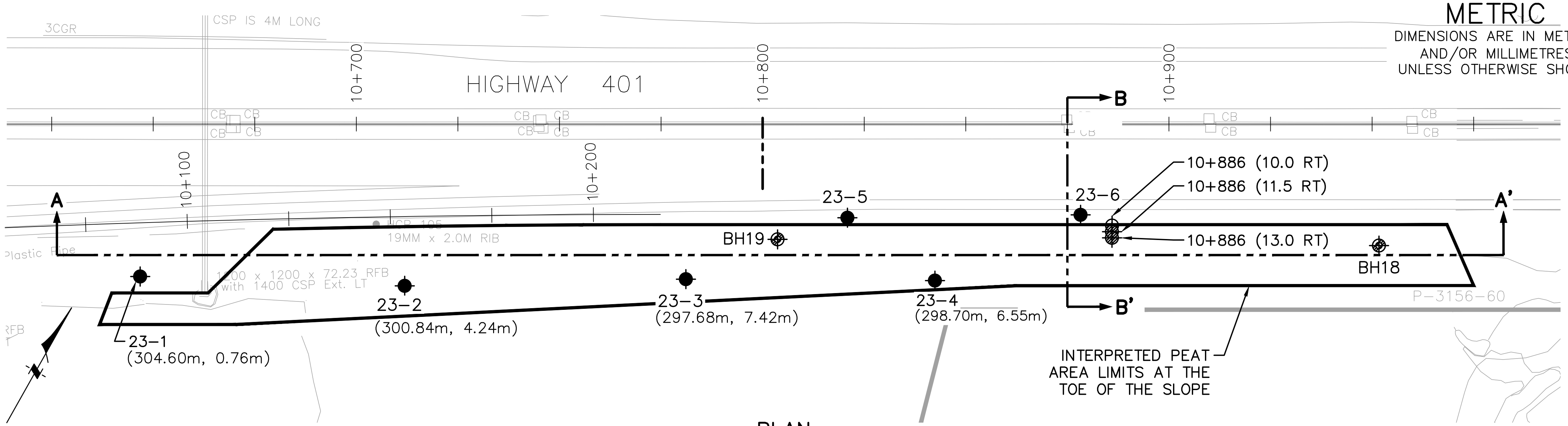
A.1 DRAWING NO. 1 – BOREHOLE LOCATION PLAN

A.2 DRAWING NO. 2 – INTERPRETED CROSS-SECTION

A.3 CONTRACT 2003-3028 PAVEMENT SECTION

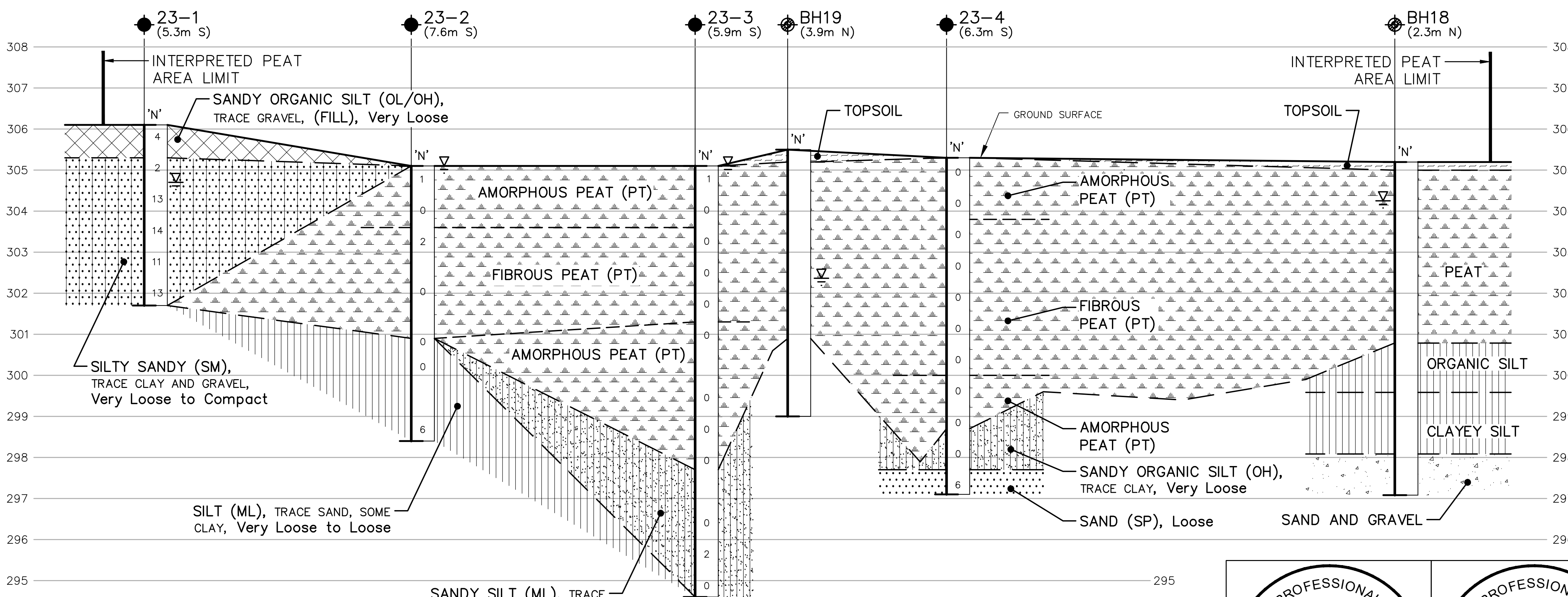
A.4 SITE PHOTOS

METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN



PLAN

SCALE
12.5m 0 12.5 25.0m



CROSS SECTION A–A'

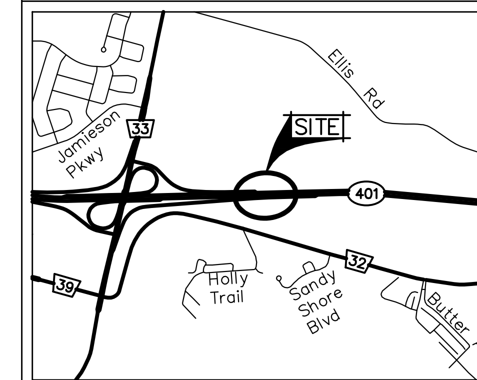
SCALE
12.5m 0 12.5 25.0m HORIZONTAL
1.25m 0 1.25 2.5m VERTICAL

PLATE No
CONT 2020–3032
WP 3222–15–00

HIGHWAY 401
CAMBRIDGE, ONTARIO
BOREHOLE LOCATIONS & SOIL STRATA

SHEET –

Stantec



KEY PLAN
500 m 0 500 1000 m

LEGEND

(symbol)	Approximate Borehole Location (Stantec, 2023)
(symbol)	Approximate Borehole Location (Golder, 2013)
(symbol)	Approximate Borehole Location (McCormick Rankin, 2003)
(5.3m S)	Offset from Cross Section Line A-A'
N	Blows/0.3m (Std Pen Test, 475 J/blow)
(symbol)	WL at time of investigation 2013 & 2023
(symbol)	Interpreted Peat Area (at Surface Based on Visual Inspection)
(298.70m, 6.55m)	Elevation of Bottom Limit of the Peat Layer, Thickness of Peat in meters

No	ELEVATION	MTM ZONE 10 COORDINATES NORTH	EAST
23–1	306.1	4 809 572.6	241 965.9
23–2	305.1	4 809 602.6	242 023.7
23–3	305.1	4 809 638.0	242 083.2
23–4	305.3	4 809 667.8	242 136.8
23–5	306.3	4 809 670.7	242 110.4
23–6	306.4	4 809 699.5	242 160.0
BH18	305.2	4 809 729.0	242 227.7
BH19	305.5	4 809 657.6	242 098.0

NOTE: The complete foundation investigation and design report for this project and other related documents may be examined at the Engineering Materials Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with the conditions of Section 102–2 of Form 100.

LICENSED PROFESSIONAL ENGINEER
R. GHASSEMI
2023-12-08
PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER
J.G.A.R. HACHÉ
2023-12-08
PROVINCE OF ONTARIO

REVISIONS DATE	BY	DESCRIPTION

GEOCRES No 40P08–299

HWY No 401			DIST
SUBM'D RG	CHECKED	DATE 2023–11–22	SITE
DRAWN GBB	CHECKED	APPROVED	DWG 1

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MINISTRY OF TRANSPORTATION, ONTARIO
PH-D-707 88-05

METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN

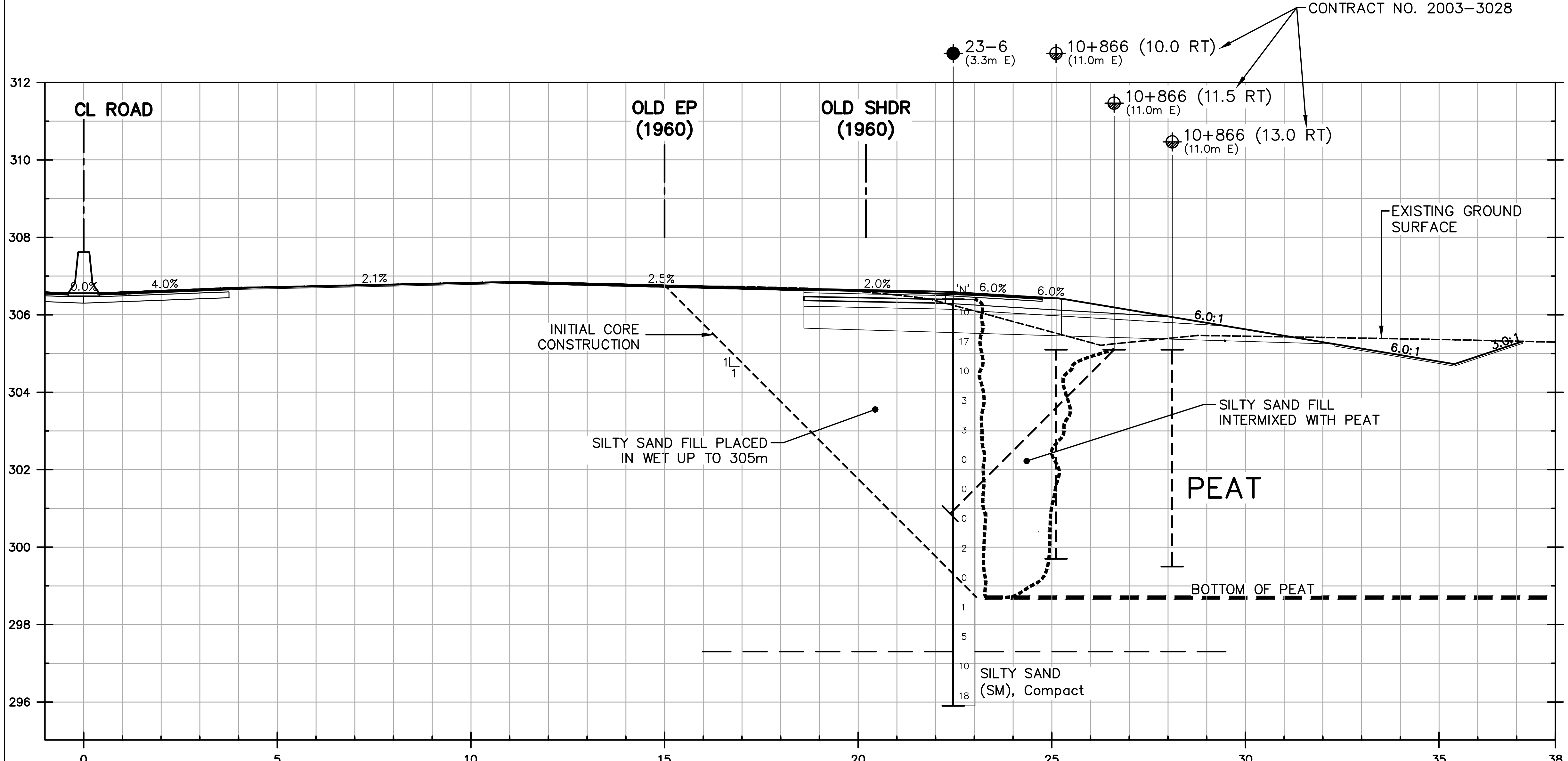
PLATE No

CONT 2020-3032
WP 3222-15-00

HIGHWAY 401
CAMBRIDGE, ONTARIO
INTERPRETED CROSS SECTION

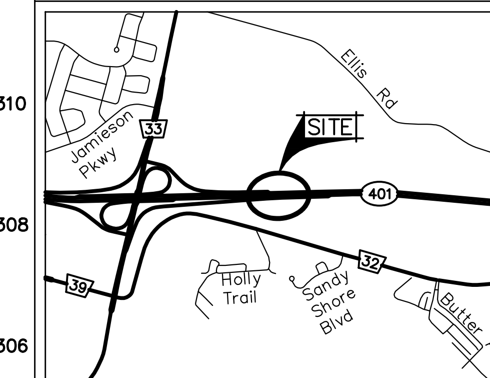
SHEET -

Stantec



CROSS SECTION B-B'

SCALE 1.25m 0 1.25 2.5m



KEY PLAN

500 m 0 500 1000 m

LEGEND

- Approximate Borehole Location (Stantec, 2023)
- Approximate Borehole Location (McCormick Rankin, 2003)
- (3.3m E) Offset from Cross Section Line B-B"

No	ELEVATION	MTM ZONE 10 COORDINATES NORTH	EAST
23-1	306.1	4 809 572.6	241 965.9
23-2	305.1	4 809 602.6	242 023.7
23-3	305.1	4 809 638.0	242 083.2
23-4	305.3	4 809 667.8	242 136.8
23-5	306.3	4 809 670.7	242 110.4
23-6	306.4	4 809 699.5	242 160.0
BH18	305.2	4 809 729.0	242 227.7
BH19	305.5	4 809 657.6	242 098.0

NOTE: The complete foundation investigation and design report for this project and other related documents may be examined at the Engineering Materials Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with the conditions of Section 102-2 of Form 100.

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J.G.A.R. HACHÉ
2023-12-08
PROVINCE OF ONTARIO

REVISIONS | DATE | BY | DESCRIPTION

GEOCRES No 40P08-299

HWY No 401 | DIST
SUBM'D RG | CHECKED | DATE 2023-11-22 | SITE
DRAWN GBB | CHECKED | APPROVED | DWG 2

METRIC

PLATE No
CONT No 2003-3028
WP No 1-00-00

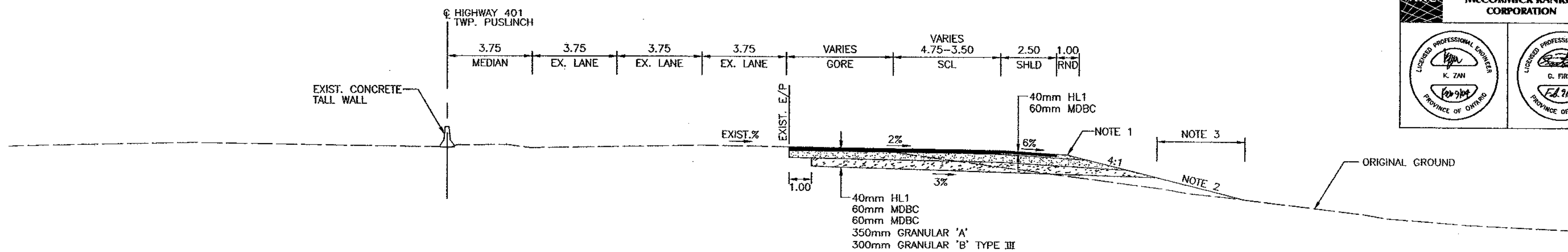
SHEET 116

TYPICAL SECTIONS

McCORMICK RANKIN CORPORATION

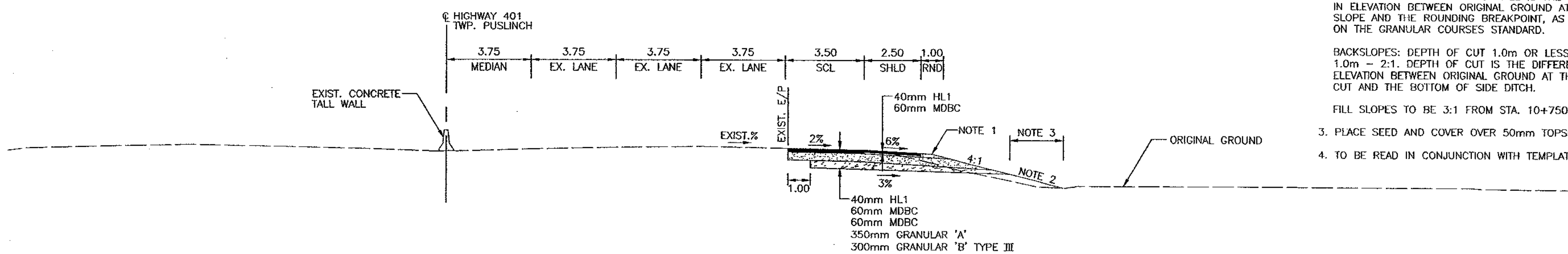
LICENSED PROFESSIONAL ENGINEER K. ZAN PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER G. FIRTH PROVINCE OF ONTARIO



HIGHWAY 401 WIDENING FOR SCL (S-E RAMP)

STA. 10+618.3 TO STA. 10+843.8 (TOWNSHIP OF PUSLINCH)
N.T.S.



HIGHWAY 401 WIDENING FOR SCL (S-E RAMP)

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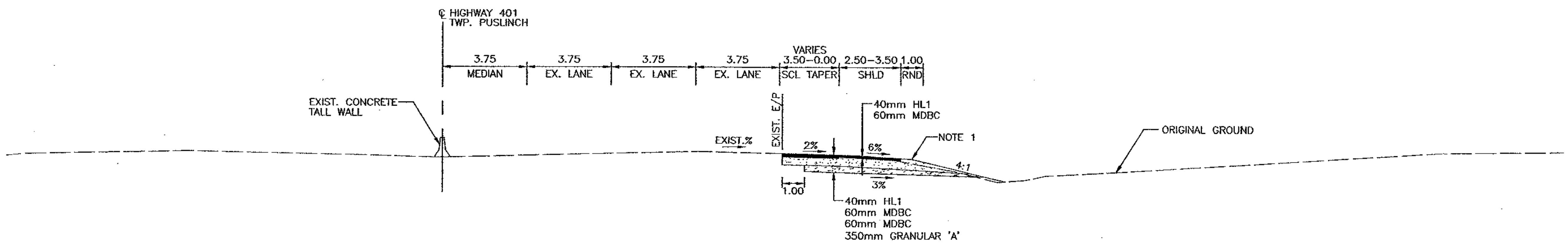
N.T.S.



HIGHWAY 401 WIDENING FOR SCL (S-E RAMP)

STA. 11+028.3 TO STA. 11+118.3 (TOWNSHIP OF PUSLINCH)
N.T.S.

NOTES:

1. GRANULAR SEALANT TO BE APPLIED PER OPSD 210.07.
2. FILL SLOPES; HEIGHT OF FILL 1.0m OR LESS - 4:1, OVER 1.0m - 2:1. HEIGHT OF FILL IS THE DIFFERENCE IN ELEVATION BETWEEN ORIGINAL GROUND AT THE TOE OF SLOPE AND THE ROUNDING BREAKPOINT, AS ESTABLISHED ON THE GRANULAR COURSES STANDARD.

   BACKSLOPES: DEPTH OF CUT 1.0m OR LESS - 3:1 OVER 1.0m - 2:1. DEPTH OF CUT IS THE DIFFERENCE IN ELEVATION BETWEEN ORIGINAL GROUND AT THE BROW OF CUT AND THE BOTTOM OF SIDE DITCH.

   FILL SLOPES TO BE 3:1 FROM STA. 10+750 TO STA. 10+950.
3. PLACE SEED AND COVER OVER 50mm TOPSOIL.
4. TO BE READ IN CONJUNCTION WITH TEMPLATES.

MINISTRY OF TRANSPORTATION, ONTARIO PH-D-707 86-05

FILE LOCATION-S:\4673\
DRAWING NAME: H4673T03.DWG
DRAWN BY: D. CAMPBELL
MODIFIED: 2004/01/21 3:48:23
REVISED BY-BJM Revised

Stantec	Foundation Investigation and Design Report MTO Highway 401 Improvements from Hespeler Road to Townline Road, Stage 4A, Muskeg/Organic Subgrade	165000897

Photo No. 1: BH23-1

Photo No. 2: BH23-1

Photo No. 3: BH23-1

Photo No. 4: Between BH23-1 and BH23-2

Photo No. 5: Between BH23-1 and BH23-2

Stantec	Foundation Investigation and Design Report MTO Highway 401 Improvements from Hespeler Road to Townline Road, Stage 4A, Muskeg/Organic Subgrade	165000897

Photo No. 6: BH23-2

Photo No. 7: BH23-2

Photo No. 8: BH23-2

Photo No. 9: Between BH23-2 and BH23-3

Photo No. 10: Between BH23-2 and BH23-3

	
Photo No. 11: BH23-3	**Photo No. 12: BH23-3**

Photo No. 13: BH23-4

Photo No. 14: BH23-4

Photo No. 15: BH23-5

Photo No. 16: BH23-5

Photo No. 17: BH23-6

Photo No. 18: BH23-6

		
Photo No. 19: East of BH23-6	**Photo No. 20: East of BH23-6**	**Photo No. 21: East of BH23-6**

APPENDIX B

B.1 SYMBOLS AND TERMS USED ON BOREHOLE RECORDS

B.2 RECORDS OF BOREHOLE

B.3 CONTRACT 2003-3028 PAVEMENT BOREHOLE RECORDS

SYMBOLS AND TERMS USED ON BOREHOLE AND TEST PIT RECORDS

SOIL DESCRIPTION

Terminology describing common soil genesis:

Rootmat	- vegetation, roots and moss with organic matter and topsoil typically forming a mattress at the ground surface
Topsoil	- mixture of soil and humus capable of supporting vegetative growth
Peat	- mixture of visible and invisible fragments of decayed organic matter
Till	- unstratified glacial deposit which may range from clay to boulders
Fill	- material below the surface identified as placed by humans (excluding buried services)

Terminology describing soil structure:

Desiccated	- having visible signs of weathering by oxidization of clay minerals, shrinkage cracks, etc.
Fissured	- having cracks, and hence a blocky structure
Varved	- composed of regular alternating layers of silt and clay
Stratified	- composed of alternating successions of different soil types, e.g. silt and sand
Layer	- > 75 mm in thickness
Seam	- 2 mm to 75 mm in thickness
Parting	- < 2 mm in thickness

Terminology describing soil types:
The classification of soil types are made on the basis of grain size and plasticity in accordance with the Unified Soil Classification System (USCS) (ASTM D 2487 or D 2488) which excludes particles larger than 75 mm. For particles larger than 75 mm, and for defining percent clay fraction in hydrometer results, definitions proposed by Canadian Foundation Engineering Manual, 4th Edition are used. The USCS provides a group symbol (e.g. SM) and group name (e.g. silty sand) for identification.

Terminology describing cobbles, boulders, and non-matrix materials (organic matter or debris):
Terminology describing materials outside the USCS, (e.g. particles larger than 75 mm, visible organic matter, and construction debris) is based upon the proportion of these materials present:

Trace, or occasional	Less than 10%
Some	10-20%
Frequent	> 20%

Terminology describing compactness of cohesionless soils:
The standard terminology to describe cohesionless soils includes compactness (formerly "relative density"), as determined by the Standard Penetration Test (SPT) N-Value - also known as N-Index. The SPT N-Value is described further on page 3. A relationship between compactness condition and N-Value is shown in the following table.

Compactness Condition	SPT N-Value
Very Loose	<4
Loose	4-10
Compact	10-30
Dense	30-50
Very Dense	>50

Terminology describing consistency of cohesive soils:
The standard terminology to describe cohesive soils includes the consistency, which is based on undrained shear strength as measured by *in situ* vane tests, penetrometer tests, or unconfined compression tests. Consistency may be crudely estimated from SPT N-Value based on the correlation shown in the following table (Terzaghi and Peck, 1967). The correlation to SPT N-Value is used with caution as it is only very approximate.

Consistency	Undrained Shear Strength		Approximate SPT N-Value
	kips/sq.ft.	kPa	
Very Soft	<0.25	<12.5	<2
Soft	0.25 - 0.5	12.5 - 25	2-4
Firm	0.5 - 1.0	25 - 50	4-8
Stiff	1.0 - 2.0	50 – 100	8-15
Very Stiff	2.0 - 4.0	100 - 200	15-30
Hard	>4.0	>200	>30

ROCK DESCRIPTION

Except where specified below, terminology for describing rock is as defined by the International Society for Rock Mechanics (ISRM) 2007 publication "The Complete ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 1974-2006"

Terminology describing rock quality:

RQD	Rock Mass Quality
0-25	*Very Poor Quality*
25-50	*Poor Quality*
50-75	*Fair Quality*
75-90	*Good Quality*
90-100	*Excellent Quality*

Alternate (Colloquial) Rock Mass Quality	
Very Severely Fractured	*Crushed*
Severely Fractured	*Shattered or Very Blocky*
Fractured	*Blocky*
Moderately Jointed	*Sound*
Intact	*Very Sound*

RQD (Rock Quality Designation) denotes the percentage of intact and sound rock retrieved from a borehole of any orientation. All pieces of intact and sound rock core equal to or greater than 100 mm (4 in.) long are summed and divided by the total length of the core run. RQD is determined in accordance with ASTM D6032.

SCR (Solid Core Recovery) denotes the percentage of solid core (cylindrical) retrieved from a borehole of any orientation. All pieces of solid (cylindrical) core are summed and divided by the total length of the core run (It excludes all portions of core pieces that are not fully cylindrical as well as crushed or rubble zones).

Fracture Index (FI) is defined as the number of naturally occurring fractures within a given length of core. The Fracture Index is reported as a simple count of natural occurring fractures.

Terminology describing rock with respect to discontinuity and bedding spacing:

Spacing (mm)	Discontinuities	Bedding
>6000	*Extremely Wide*	-
2000-6000	*Very Wide*	*Very Thick*
600-2000	*Wide*	*Thick*
200-600	*Moderate*	*Medium*
60-200	*Close*	*Thin*
20-60	*Very Close*	*Very Thin*
<20	*Extremely Close*	*Laminated*
<6	-	*Thinly Laminated*

Terminology describing rock strength:

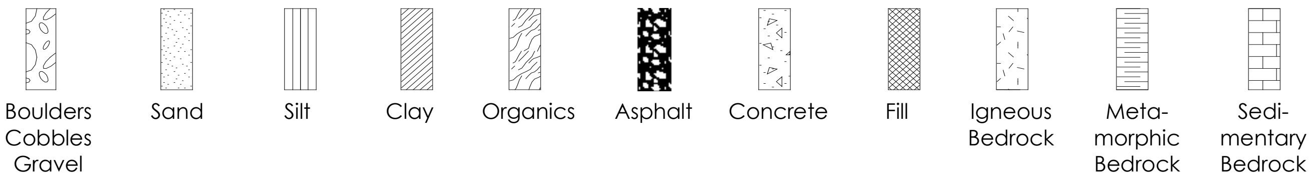
Strength Classification	Grade	Unconfined Compressive Strength (MPa)
Extremely Weak	R0	<1
Very Weak	R1	1 – 5
Weak	R2	5 – 25
Medium Strong	R3	25 – 50
Strong	R4	50 – 100
Very Strong	R5	100 – 250
Extremely Strong	R6	>250

Terminology describing rock weathering:

Term	Symbol	Description
Fresh	W1	No visible signs of rock weathering. Slight discoloration along major discontinuities
Slightly	W2	Discoloration indicates weathering of rock on discontinuity surfaces. All the rock material may be discolored.
Moderately	W3	Less than half the rock is decomposed and/or disintegrated into soil.
Highly	W4	More than half the rock is decomposed and/or disintegrated into soil.
Completely	W5	All the rock material is decomposed and/or disintegrated into soil. The original mass structure is still largely intact.
Residual Soil	W6	All the rock converted to soil. Structure and fabric destroyed.

STRATA PLOT

Strata plots symbolize the soil or bedrock description. They are combinations of the following basic symbols. The dimensions within the strata symbols are not indicative of the particle size, layer thickness, etc.



SAMPLE TYPE

SS	Split spoon sample (obtained by performing the Standard Penetration Test)
ST	Shelby tube or thin wall tube
DP	Direct-Push sample (small diameter tube sampler hydraulically advanced)
PS	Piston sample
BS	Bulk sample
HQ, NQ, BQ, etc.	Rock core samples obtained with the use of standard size diamond coring bits.

WATER LEVEL MEASUREMENT

▼ measured in standpipe, piezometer, or well

▽ inferred

RECOVERY

For soil samples, the recovery is recorded as the length of the soil sample recovered. For rock core, recovery is defined as the total cumulative length of all core recovered in the core barrel divided by the length drilled and is recorded as a percentage on a per run basis.

N-VALUE

Numbers in this column are the field results of the Standard Penetration Test: the number of blows of a 140 pound (63.5 kg) hammer falling 30 inches (760 mm), required to drive a 2 inch (50.8 mm) O.D. split spoon sampler one foot (300 mm) into the soil. In accordance with ASTM D1586, the N-Value equals the sum of the number of blows (N) required to drive the sampler over the interval of 6 to 18 in. (150 to 450 mm). However, when a 24 in. (610 mm) sampler is used, the number of blows (N) required to drive the sampler over the interval of 12 to 24 in. (300 to 610 mm) may be reported if this value is lower. For split spoon samples where insufficient penetration was achieved and N-Values cannot be presented, the number of blows are reported over sampler penetration in millimetres (e.g. 50/75). Some design methods make use of N-values corrected for various factors such as overburden pressure, energy ratio, borehole diameter, etc. No corrections have been applied to the N-values presented on the log.

DYNAMIC CONE PENETRATION TEST (DCPT)

Dynamic cone penetration tests are performed using a standard 60 degree apex cone connected to 'A' size drill rods with the same standard fall height and weight as the Standard Penetration Test. The DCPT value is the number of blows of the hammer required to drive the cone one foot (300 mm) into the soil. The DCPT is used as a probe to assess soil variability.

OTHER TESTS

S	Sieve analysis
H	Hydrometer analysis
k	Laboratory permeability
γ	Unit weight
G_s	Specific gravity of soil particles
CD	Consolidated drained triaxial
CU	Consolidated undrained triaxial with pore pressure measurements
UU	Unconsolidated undrained triaxial
DS	Direct Shear
C	Consolidation
Q_U	Unconfined compression
I_p	Point Load Index (I_p on Borehole Record equals $I_p(50)$ in which the index is corrected to a reference diameter of 50 mm)

	Single packer permeability test; test interval from depth shown to bottom of borehole
	Double packer permeability test; test interval as indicated
	Falling head permeability test using casing
	Falling head permeability test using well point or piezometer

Ministry of Transportation
Ontario

RECORD OF BOREHOLE No BH23-01

METRIC

W.P. 3222-15-00 | LOCATION MTM Zone 10 Coordinates N: 4811683.14 E: 484880.69 | ORIGINATED BY WT & JM

DIST ___ HWY 401 | BOREHOLE TYPE Direct push head using Massenza MSPT | COMPILED BY WT

DATUM Geodetic | DATE 2023.03.23 - 2023.03.23 | LATITUDE 43.423425 | LONGITUDE -80.276008 | CHECKED BY RG

ELEV / DEPTH (m)	DESCRIPTION	STRAT PLOT	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
306.1													
0.0	FILL: sandy organic silt, trace gravel (OL/OH) Very loose Brown Moist	Fill	1	SS	4		306	1063.6					
305.4 / 0.8	SILTY SAND, trace clay, trace gravel (SM) Very loose to Compact Brown Moist to Wet	Silty sand	2	SS	2	▽ (1.4 m)	305						
			3	SS	13		304						
			4	SS	14								
			5	SS	11		303			2	81	15	2
	Some gravel below 3.8 m depth		6	SS	13		302						
301.7 / 4.4	End of borehole. Unstabilized groundwater level was observed at 1.4 m depth during drilling.												

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

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

RECORD OF BOREHOLE No BH23-02

METRIC

W.P. 3222-15-00	LOCATION MTM Zone 10 Coordinates N: 4811715.20 E: 484937.44		ORIGINATED BY WT & JM
DIST	HWY 401	BOREHOLE TYPE Direct push head using Massenza MSPT	COMPILED BY WT
DATUM Geodetic	DATE 2023.03.23 - 2023.03.24	LATITUDE 43.4237 LONGITUDE -80.275297	CHECKED BY RG

ELEV / DEPTH (m)	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	NATURAL MOISTURE CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
305.1 / 0.0	FILL: amorphous peat (PT) H6 Black	1	SS	1	331.6	
		2	SS	0	434.7	
303.6 / 1.5	FIBROUS PEAT (PT) H2 to H3 Black	3	SS	2	621.8	
		4	SS	0	940.2	
		5	SS	0	625	
300.8 / 4.2	SILT, trace sand, some clay (ML) Very loose to loose Grey Wet	6	SS	0		0 7 82 11 Non-plastic
		7	SS	6		Non-plastic
298.4 / 6.7	End of borehole Unstabilized groundwater level was observed at the surface at the time of driling.					

Column headings: SOIL PROFILE; SAMPLES; GROUND WATER CONDITIONS; ELEVATION SCALE (305, 304, 303, 302, 301, 300, 299); DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa — ○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE (20, 40, 60, 80, 100); PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) (20, 40, 60); UNIT WEIGHT γ kN/m³.

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

RECORD OF BOREHOLE No BH23-03

METRIC

W.P. 3222-15-00 LOCATION MTM Zone 10 Coordinates N: 4811752.74 E: 484995.63 ORIGINATED BY WT & JM
DIST ___ HWY 401 BOREHOLE TYPE Direct push head using Massenza MSPT COMPILED BY WT
DATUM Geodetic DATE 2023.03.24 - 2023.03.28 LATITUDE 43.424022 LONGITUDE -80.274567 CHECKED BY RG

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
305.1 / 0.0	FILL: amorphous peat (PT) H6 Black	1	SS	1*		
		2	SS	0	492.6	
303.6 / 1.5	FIBROUS PEAT (PT) H2 to H3 Black to brown Saturated	3	SS	0	1010.3	
		4	SS	0	732.1	
		5	SS	0	688.7	
301.3 / 3.8	AMORPHOUS PEAT (PT) H7 to H8 Black to brown	6	SS	0		
		7	TW		972.6	
		8	SS	0	812	
		9	SS	0	594.6	
		10	SS	0	1008.9; 178.3	
297.7 / 7.4	SANDY SILT, trace gravel, trace clay (ML) Very loose Grey Wet	11	SS	0	(plotted)	2 30 60 8
		12	SS	2		
		13	SS	0		
294.6 / 10.5	End of borehole					

End of borehole
Unstabilized groundwater level was observed at the surface at the time of driling.

* Split Spoon sampler resulted in zero recovery (SS1).
Consolidation test was performed on TW7.

Ground water conditions: ▽ at surface.

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

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

Ministry of Transportation Ontario

Foundation Design

RECORD OF BOREHOLE No BH23-04

METRIC

W.P. 3222-15-00	LOCATION MTM Zone 10 Coordinates N: 4811784.45 E: 485048.11		ORIGINATED BY WT & JM
DIST ____ HWY 401	BOREHOLE TYPE Direct push head using Massenza MSPT		COMPILED BY WT
DATUM Geodetic	DATE 2023.03.28 - 2023.03.29	LATITUDE 43.424297 LONGITUDE -80.273911	CHECKED BY RG

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	NATURAL MOISTURE CONTENT w (%)
305.3 / 0.0	FILL: amorphous peat (PT) H6 Black	1	SS	0	305	444.4
		2	SS	0	304	624.3
303.8 / 1.5	FIBROUS PEAT (PT) H2 to H3 Black	3	SS	0*		
		4	SS	0	303	823.2
	A 130 mm thick wood piece (H1) was encountered in Shelby tube at 3.7 m depth	5	TW	0	302	
		6	SS	0	301	968.2
		7	SS	0		968.6
299.9 / 5.3	AMORPHOUS PEAT (PT) H7 to H8 Brown Black from 5.6 m to 6.0 m depth	8	TW	0	300	898
		9	SS	0	299	1068.9
298.7 / 6.6	SANDY ORGANIC SILT, trace clay, trace gravel (OH) Very loose Grey Wet	10	SS	0	298	171.7
297.6 / 7.6	SAND (SP) Loose Grey Wet	11	SS	6		~20 (plotted)
297.0 / 8.2	End of borehole Unstabilized groundwater level was observed at the surface at the time of drilling. * Split Spoon sampler resulted in zero recovery (SS3). Consolidation test was performed on TW8.					

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 × LAB VANE 20 40 60 80 100; PLASTIC LIMIT w_P, NATURAL MOISTURE CONTENT w, LIQUID LIMIT w_L, WATER CONTENT (%) 20 40 60; UNIT WEIGHT γ kN/m³; REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

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

Ministry of Transportation
Ontario

RECORD OF BOREHOLE No BH23-05

METRIC

W.P. 3222-15-00	LOCATION MTM Zone 10 Coordinates N: 4811786.41 E: 485021.64		ORIGINATED BY WT & JM
DIST ___ HWY 401	BOREHOLE TYPE Hollow stem auger using 3126GT Geotechnical Drill Rig		COMPILED BY WT
DATUM Geodetic	DATE 2023.03.28 - 2023.03.28	LATITUDE 43.424319 LONGITUDE -80.274236	CHECKED BY RG

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, × LAB VANE (20, 40, 60, 80, 100) | PLASTIC LIMIT w_P, NATURAL MOISTURE CONTENT w, LIQUID LIMIT w_L — WATER CONTENT (%) (20, 40, 60) | UNIT WEIGHT γ kN/m³ | REMARKS & GRAIN SIZE DISTRIBUTION (%)

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT	GR	SA	SI	CL
306.3 / 0.0	FILL: sand and gravel (SP/GP) Compact Brown Moist to wet	Fill	1	SS	11	306					
305.6 / 0.8	FILL: sand (SP), trace to some gravel Very loose to loose Brown Moist to wet	Fill	2	SS	5	305					
			3	SS	0	304					
			4	SS	2						
303.3 / 3.1	FILL: sandy silt, trace gravel, trace clay (ML) Very loose Brown Wet	Fill	5	SS	0*	303					
			6	SS	0*	302		1	36	62	1
								Non-plastic			
	Very soft black clay with organics between 4.8 m and 5.3 m		7	SS	0		90.4				
			8	SS	3	301					
			9	SS	0	300					
	Very soft grey clayey silt between 7.1 m and 7.6 m		10	SS	1	299					
			11	SS	0						
297.9 / 8.4	SILTY SAND (SM), trace gravel, trace clay Very loose to compact Grey Wet	Silty sand	12	SS	0	298					
			13	SS	0	297		2	82	14	2
			14	SS	5	296					
			15	SS	11						
295.0 / 11.3	End of borehole * Split Spoon sampler resulted in zero recovery.										

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

ONTARIO MTO 165000897_MTO_HWY 401 IMPROVEMENT EAST OF TOWNLINE RD_20230713.GPJ ONTARIO MTO.GDT 7/13/23

RECORD OF BOREHOLE No BH23-06

METRIC

W.P. 3222-15-00 LOCATION MTM Zone 10 Coordinates N: 4811817.00 E: 485070.25 ORIGINATED BY WT & JM

DIST ____ HWY 401 BOREHOLE TYPE Hollow stem auger using 3126GT Geotechnical Drill Rig COMPILED BY WT

DATUM Geodetic DATE 2023.03.28 - 2023.03.28 LATITUDE 43.424583 LONGITUDE -80.273625 CHECKED BY RG

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
306.4 / 0.0	FILL: sand and gravel (SP/GP), trace organics, trace silt Compact Brown Moist	1	SS	10				
		2	SS	17				
		3	SS	10				
304.1 / 2.3	FILL: silty sand, trace to some gravel, trace clay (SM) Very loose to loose Brown Moist to wet	4	SS	3				
		5	SS	3				
		6	SS	0	15	54	27	4
		7	SS	0				
		8	SS	0	5	52	38	5
		9	SS	2				
		10	SS	0	8	52	33	7
		11	SS	1				
		12	SS	5				
297.2 / 9.1	SAND to SILTY SAND (SM) Compact Brown Wet	13	SS	10				
		14	SS	18				
295.9 / 10.5	End of borehole							

Column headings: SOIL PROFILE; SAMPLES; GROUND WATER CONDITIONS; ELEVATION SCALE (306 to 296); DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa: ○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE (20, 40, 60, 80, 100); PLASTIC LIMIT w_P, NATURAL MOISTURE CONTENT w, LIQUID LIMIT w_L; WATER CONTENT (%) (20, 40, 60); UNIT WEIGHT γ kN/m³; REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

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

METRIC

PLATE No
CONT No 2003–3028
WP No 1–00–00

SOILS DATA

Survey ______ Revised ______

SHEET 105

TOWNLINE ROAD WIDENING

10+100 15.7 Rt C/L

0 – 550 Dk Br Say Si Tps Tr Gr
550 – 700 Br Siy Sa Some Gr OCC Cob
700 NFP Cob And Blds

10+100 24.2 Rt C/L

0 – 200 Dk Br Say Si Tps
200 – 1.5 Lt Br Say Si Tr Gr w = 15%

10+150 27.8 Lt C/L

0 – 150 Dk Br Say Si Tps
150 – 1.0 Br Siy Sa Tr Gr Tr Tps (Fill)
1.0 – 1.5 Lt Br Say Si Tr Gr Moist to Wet

10+150 13.5 Lt C/L

0 – 600 Dk Br Say Si Tps Some Gr
600 NFP Cob And Blds

10+150 5.3 Lt C/L SH

0 – 70 Asph
70 – 1.0 Br F–Med Sa And Gr Tr Si
1.0 – 3.8 Br Say Si Some Gr Tr Tps OCC Cob
3.8 – 5.2 Br/Gry Say Si Some Gr Some Tps
5.2 – 6.0 Br Siy Sa

10+150 3.8 Lt C/L EP

0 – 185 Asph
185 – 365 Br F–Med Sa And Gr Tr Si
365 – 1.0 Br F–Med Sa And Gr Tr Si OCC Cob
1.0 – 1.5 Br Say Si And Siy Sa Some Gr

10+250 22.7 Lt C/L

0 – 150 Dk Br Say Si Tps
150 – 1.2 Br Say Si Tr Gr
1.2 – 1.5 Red–Br Siy Sa w = 10%

10+250 10.2 Lt C/L

0 – 600 Br F–Med Sa And Gr Tr Si Num Cob
600 – 1.5 Lt Br Siy Sa Some Gr Moist–Wet

10+250 7.9 Lt C/L SH

0 – 300 Br F–Med Sa And Gr Some Si*
300 – 1.3 Br F–Med Sa And Gr Tr Si Num Cob
1.3 – 2.7 Dk Br Say Si Tr Gr Tr Tps
2.7 – 3.0 Red–Br Siy Sa
* % Passing 26.5 mm = 100
19 mm = 96
4.75 mm = 48
1.18 mm = 33
300 μm = 21
75 μm = 11
NOT Accep Gran "A"

10+250 6.5 Lt C/L EP

0 – 110 Asph
110 – 170 PST
170 – 450 Br F–Med Sa And Gr Tr Si
450 – 1.5 Br F–Med Sa And Gr Tr Si Num Cob

10+295 2.6 Rt C/L EP

0 – 160 Asph
160 – 300 Br F–Med Sa And Gr Tr Si
300 – 1.0 Br F–Med Sa And Gr Tr Si OCC Cob
1.0 – 1.5 Br F–Med Sa Some Si Tr Gr

10+295 6.3 Rt C/L SH

0 – 300 Br F–Med Sa And Gr Tr Si
300 – 1.2 Br F–Med Sa And Gr OCC Cob
1.2 – 1.5 Br F–Med Sa Tr Si Tr Gr

10+350 19.4 Lt C/L

0 – 230 Dk Br Say Si Tps Tr Gr
230 – 1.5 Lt Br Siy Sa Some Gr w = 8%

10+350 8.8 Lt C/L SH

0 – 310 Br F–Med Sa And Gr Tr Si
310 – 900 Br F–Med Sa Some Gr Tr Si OCC Cob
900 – 1.5 Red–Br Say Si Some Gr Tr Cl

10+350 6.9 Lt C/L EP

0 – 180 Asph
180 – 330 Br F–Med Sa And Gr Tr Si
330 – 900 Br F–Med Sa And Gr Tr Si OCC Cob
900 – 1.5 Red–Br Siy Sa Some Gr Tr Cl*
* % Passing 4.75 mm = 83
2 mm = 63
425 μm = 53
75 μm = 36
5 μm = 15
2 μm = 12
SM MSFH

10+400 3.7 Rt C/L EP

0 – 170 Asph
170 – 440 Br F–Med Sa And Gr Tr Si
440 – 1.0 Br F–Med Sa And Gr Tr Si OCC Cob
1.0 – 1.5 Br F–Med Sa Tr Si Some Gr

10+400 6.5 Rt C/L SH

0 – 500 Br F–Med Sa And Gr Tr Si
500 – 1.0 Br F–Med Sa And Gr Tr Si OCC Cob
1.0 – 1.5 Br F–Med Sa Some Si Tr Gr

10+450 16.9 Lt C/L

0 – 250 Dk Br Say Si Tps
250 – 1.5 Lt Br Siy Sa Some Gr OCC Cob w = 8%

10+450 4.8 Lt C/L SH

0 – 250 Br Siy Sa And Gr
250 – 900 Br F–Med Sa And Gr Tr Si OCC Cob
900 – 1.5 Br F–Med Sa Tr Si Some Gr

10+450 3.2 Lt C/L EP

0 – 140 Asph
140 – 300 Br F–Med Sa And Gr Some Si*
300 – 900 Br F–Med Sa And Gr Tr Si Num Cob
900 – 1.5 Br F–Med Sa Tr Si Some Gr
* % Passing 26.5 mm = 100
19 mm = 90
4.75 mm = 58
1.18 mm = 37
300 μm = 23
75 μm = 14
NOT Accep Gran "A"

10+500 7.0 Rt C/L EP

0 – 135 Asph
135 – 240 Br F–Med Sa And Gr Tr Si
240 – 750 Br F–Med Sa And Gr Tr Si OCC Cob
750 – 1.2 Br F–Med Sa Tr Si Tr Gr

10+500 9.6 Rt C/L SH

0 – 260 Br F–Med Sa And Gr Tr Si
260 – 1.0 Red–Br Siy Sa Some Gr OCC Cob
1.0 – 1.5 Lt Br Siy Sa Tr Gr

10+535 33.0 Rt C/L
(Pinebush Road)

0 – 210 Asph
210 – 370 Br F–Med Sa And Gr Tr Si
370 – 900 Br F–Med Sa And Gr Tr Si OCC Cob
900 – 1.5 Br F–Med Sa Tr Si Tr Gr

10+575 13.9 Lt C/L

0 – 200 Dk Br Say Si Tps
200 – 1.5 Lt Br Siy Sa Some Gr

10+575 3.9 Lt C/L SH

0 – 50 Asph
50 – 150 Br Siy Sa And Gr
150 – 280 Red–Br Say Si Some Gr
280 – 1.5 Lt Br Siy Sa Tr Gr

10+575 2.5 Lt C/L

0 – 100 Asph
100 – 320 Br Siy Sa And Gr
320 – 440 Dk Br Say Si Tps
440 – 1.5 Br Siy Sa Some Gr

10+575 4.2 Rt C/L SH

0 – 100 Dk Br Siy Sa Tps Some Gr
100 – 300 Br Siy Sa And Gr
300 – 1.5 Red–Br Siy Sa Tr Gr OCC Cob

10+575 10.3 Rt C/L

0 – 200 Dk Br Say Si Tps Tr Gr
200 – 1.5 Lt Br Siy Sa Tr Gr w = 11%

10+625 13.8 Lt C/L

0 – 330 Dk Br Say Si Tps
330 – 1.5 Lt Br Siy Sa Some Gr w = 9%

10+625 3.4 Lt C/L SH

0 – 120 Asph
120 – 270 Br Siy F–Med Sa And Gr
270 – 320 Br Say Si Tr Gr
320 – 1.5 Lt Br Siy Sa

10+625 3.0 Rt C/L

0 – 120 Asph
120 – 340 Br Siy F–Med Sa And Gr
340 – 500 Dk Br Say Si Tps
500 – 1.2 Lt Br Siy Sa

10+625 4.3 Rt C/L SH

0 – 90 Dk Br Siy Sa Tps W Gr
90 – 240 Br Siy F–Med Sa And Gr
240 – 1.2 Lt Br Say Si Some Gr
1.2 – 1.5 Lt Br Siy Sa

10+625 10.0 Rt C/L

0 – 240 Dk Br Say Si Tps
240 – 1.5 Lt Br Say Si Some Gr w = 5%

HIGHWAY 401 EASTBOUND

Datum: Existing EP

10+700 0.3 Lt of Rt EP

0 – 300 Asph
300 – 1.5 Br F–Co Sa And Gr Some Si*
* % Passing 26.5 mm = 100
19 mm = 99
4.75 mm = 83
1.18 mm = 61
300 μm = 41
75 μm = 19
MWD = 2.38 t/m3
MDD = 2.23 t/m3
wopt = 6%
NOT Accep Gran "A" or "B"

10+700 1.5 Rt of Rt EP MSH

0 – 150 Asph
150 – 1.5 Br F–Co Sa And Gr W Si

10+700 3.0 Rt of Rt EP EPS

0 – 70 Asph
70 – 1.5 Br F–Co Sa And Gr W Si

10+700 8.0 Rt of Rt EP

0 – 1.5 Br F–Med Sa Tr Gr Tr Si

10+800 0.3 Lt of Rt EP

0 – 350 Asph
350 – 1.5 Br F–Co Sa And Gr W Si w = 4%

10+800 3.0 Rt of Rt EP EPS

0 – 220 Asph
220 – 1.5 Br F–Co Sa And Gr W Si

10+800 6.8 Rt of Rt EP

0 – 1.5 Br F–Med Sa And Gr Tr Si OCC Cob
Moist to Wet

10+800 13.0 Rt of Rt EP

0 – 4.5 Dk Br Fib Peat Sat
4.5 – 6.0 Gry Say Si Tr Gr Sat
Fr Wat @ 2.4

10+836 8.3 Rt of Rt EP

0 – 3.2 Br Sa And Gr Some Si
3.2 – 5.3 Gry Sa And Gr Some Si Tr Org

10+836 15.0 Rt of Rt EP

0 – 7.2 Blk Peat Moist to Sat
7.2 NFP Poss Wd

10+850 9.9 Rt of Rt EP

0 – 2.1 Blk Peat
w = 204% @ 2.1

10+850 11.4 Rt of Rt EP

0 – 3.6 Blk Peat
w = 420% @ 2.1
w = 714% @ 3.6

10+850 16.4 Rt of Rt EP

0 – 6.0 Blk Peat
w = 737% @ 3.6
w = 1013% @ 6.0

10+886 8.8 Rt of Rt EP

0 – 1.5 Br/Gry Siy Sa Some Gr Moist to Wet
1.5 NFP Poss Bld

10+886 10.0 Rt of Rt EP
(Toe of Embankment Slope)

0 – 500 Blk Peat Wet
500 – 700 Br Si And Sa Tr Gr Sat
700 – 2.7 Dk Br/Blk Peat Sat
2.7 – 2.8 Lt Gry Siy Cl Wet
2.8 – 2.9 Br/Gry Say Si Tr Gr Sat
2.9 – 3.6 Blk Peat Sat
3.6 – 3.7 Seams of Br Sa Tr Si Tr Gr Sat
3.7 – 5.3 Blk Peat Sat
5.3 – 5.4 Br/Gry Siy Sa Sat
Fr Wat @ 200

10+886 10.0 Rt of Rt EP @ 45°
(Toe of Embankment Slope)

0 – 1.1 Blk Peat Moist to Sat
1.1 – 1.2 Br/Gry Siy Sa Sat
1.2 NFP

10+886 10.4 Rt of Rt EP @ 35°

0 – 1.0 Dk Br/Br Peat Tr Sa Tr Si Moist to Sat
1.0 – 1.2 Seams of Br Sa Some Gr Sat
1.2 – 2.1 Peat Sat
2.1 – 2.4 Gry Sa And Gr Tr Si Sat
2.4 NFP

10+886 11.5 Rt of Rt EP @ 45°

0 – 500 Blk Peat Sat
500 – 900 Br Siy Sa Tr Gr Sat
900 – 5.3 Blk Peat Sat
5.3 – 5.9 Blk Peat Tr Sa Tr Gr Sat
5.9 – 6.0 Gry Siy Sa Sat

10+886 13.0 Rt of Rt EP

0 – 5.5 Dk Blk/Br Peat Moist to Sat
5.5 – 5.6 Gry Siy Sa Sat

10+900 0.3 Lt of Rt EP

0 – 345 Asph
345 – 1.5 Br F–Co Sa And Gr W Si

10+900 1.5 Rt of Rt EP MSH

0 – 245 Asph
245 – 1.5 Br F–Co Sa And Gr Some Si* w = 4%
* % Passing 26.5 mm = 97
19 mm = 89
4.75 mm = 56
1.18 mm = 41
300 μm = 29
75 μm = 15
NOT Accep Gran "A" or "B"

10+900 3.0 Rt of Rt EP EPS

0 – 215 Asph
215 – 1.5 Br F–Co Sa And Gr W Si

10+900 7.1 Rt of Rt EP

0 – 650 Br Siy Sa And Gr
650 – 2.7 Gry Siy Sa And Gr Tr Org OCC Cob
2.7 – 3.0 Lt Br Siy Sa Tr Gr

10+900 10.7 Rt of Rt EP

0 – 3.7 Blk Peat
w = 329% @ 3.0
w = 431% @ 3.7

METRIC

PLATE No

CONT No 2003-3028

WP No 1-00-00

SOILS DATA

SHEET 106

HIGHWAY 401 EASTBOUND

10+900 13.0 Rt of Rt EP

0 - 5.7 Dk Br Fib Peat Wet
5.7 - 5.8 Gry Say Si Tr Gr Sat

10+900 14.9 Rt of Rt EP

0 - 3.7 Blk Peat
w = 691% @ 3.7

10+900 15.2 Rt of Rt EP

0 - 6.0 Blk Peat
w = 811% @ 6.0

10+900 22.5 Rt of Rt EP

0 - 3.4 Blk Peat
w = 651% @ 3.4

10+930 8.7 Rt of Rt EP

0 - 600 Br Sa And Gr Tr Si
600 - 1.5 Br Say Si Some Gr
1.5 - 5.2 Gry Say Si Some Gr Moist to Wet
Fr Wat @ 200

10+930 10.2 Rt of Rt EP

0 - 400 Blk Peat Moist
400 - 600 Br/Gry Say Si Some Gr Tr Org
600 - 3.2 Blk Peat Sat
3.2 - 3.3 Br Say Si Sat

10+930 11.9 Rt of Rt EP
(Toe of Embankment Slope)

0 - 5.0 Blk Peat Moist to Sat
5.0 - 5.1 Br Sa Tr Si Tr Gr

10+930 11.9 Rt of Rt EP @ 45°
(Toe of Embankment Slope)

0 - 300 Blk Peat Tr Sa Tr Gr Tr Si Moist
300 - 4.0 Blk Peat Moist to Sat
4.0 - 4.2 Br Say Si Tr Gr

10+930 14.9 Rt of Rt EP

0 - 5.2 Blk Peat Sat
5.2 - 5.3 Br Say Si Sat

11+000 0.3 Lt of Rt EP

0 - 365 Asph
365 - 1.5 Br F-Co Sa And Gr W Si

11+000 3.0 Rt of Rt EP EPS

0 - 200 Asph
200 - 1.5 Br F-Co Sa And Gr W Si w = 5%

11+000 8.0 Rt of Rt EP

0 - 50 Dk Br Siy Sa Tps
50 - 1.5 Lt Br Siy Sa Tr Gr

11+000 13.0 Rt of Rt EP

0 - 300 Dk Br Siy Sa Tps Tr Gr
300 - 1.5 Lt Br Siy Sa Tr Gr

11+100 0.3 Lt of Rt EP

0 - 305 Asph
305 - 1.5 Br F-Co Sa And Gr Some Si* w = 2%
* % Passing 26.5 mm = 96
19 mm = 87
4.75 mm = 49
1.18 mm = 31
300 μm = 20
75 μm = 11
NOT Accep Gran "A" or "B"

11+100 Rt SH EP

0 - 200 Asph
200 - 1.7 Br F-Co Sa And Gr W Si
1.7 - 2.3 Br Si And Sa Tr Gr Wet*
N = 9 (1.7-2.3) w = 11%
* % Passing 4.75 mm = 92
2 mm = 88
425 μm = 77
75 μm = 46
5 μm = 11
2 μm = 6
Non Plastic
SM MSFH

HIGHWAY 401 WESBOUND

Datum: Existing EP

21+900 3.0 Lt of Lt EP EPS

0 - 185 Asph
185 - 600 Br F-Co Sa And Gr W Si
600 - 1.5 Br Siy F Sa

21+900 0.3 Rt of Lt EP

0 - 330 Asph
330 - 760 Br F-Co Sa And Gr W Si
760 - 1.5 Br Siy F Sa w = 6%

22+000 13.0 Lt of Lt EP

0 - 250 Dk Br Say Si Tps
250 - 650 Lt Br Say Si Tr Gr

22+000 9.0 Lt of Lt EP

0 - 300 Br Say Si Tps Some Gr
300 - 1.5 Lt Br Say Si Some Gr Moist-Wet

22+000 3.0 Lt of Lt EP EPS

0 - 190 Asph
190 - 560 Br F-Co Sa And Gr W Si
560 - 1.0 Br F Sa W Si
1.0 - 1.1 Dk Br Say Si Tps
1.1 - 1.5 Br Siy Sa Tr Cl* w = 17%
* % Passing 4.75 mm = 97
2 mm = 93
425 μm = 80
75 μm = 38
5 μm = 8
2 μm = 3
SM MSFH

22+000 0.3 Rt of Lt EP

0 - 290 Asph
290 - 740 Br F-Co Sa And Gr W Si
740 - 1.0 Br F Sa W Si
1.0 - 1.5 Dk Br Say Si Tr Cl w = 16%

22+100 13.0 Lt of Lt EP

0 - 150 Dk Br Say Si Tps
150 - 600 Br Say Si Tr Gr
600 - 1.5 Lt Br Siy Sa

22+100 8.5 Lt of Lt EP

0 - 300 Dk Br Siy Sa Tps Some Gr
300 - 1.5 Lt Br Say Si Some Gr Moist-Wet w = 15%

22+100 3.0 Lt of Lt EP EPS

0 - 210 Asph
210 - 1.3 Br F-Co Sa And Gr W Si
1.3 - 1.5 Br Say Si Tr Cl Wet

22+100 1.5 Lt of Lt EP MSH

0 - 240 Asph
240 - 1.5 Br F-Co Sa And Gr W Si

22+100 0.3 Rt of Lt EP

0 - 415 Asph
415 - 1.5 Br F-Co Sa And Gr W Si w = 4%

22+200 13.0 Lt of Lt EP

0 - 200 Dk Br Say Si Tps
200 - 1.5 Lt Br Siy Sa Tr Gr

22+200 10.0 Lt of Lt EP

0 - 200 Dk Br Say Si Tps Tr Gr
200 - 1.5 Lt Br Siy Sa Tr Gr

22+200 3.0 Lt of Lt EP EPS

0 - 200 Asph
200 - 1.5 Br F-Co Sa And Gr W Si

22+200 0.3 Rt of Lt EP

0 - 380 Asph
380 - 1.5 Br F-Co Sa And Gr W Si* w = 4%
* % Passing 26.5 mm = 100
19 mm = 99
4.75 mm = 75
1.18 mm = 59
300 μm = 43
75 μm = 23
NOT Accep Gran "A" or "B"

23+300 15.0 Lt of Lt EP

0 - 200 Dk Br Say Si Tps Tr Gr
200 - 1.5 Lt Br Siy Sa Tr Gr w = 11%

22+300 11.0 Lt of Lt EP

0 - 230 Dk Br Say Si Tps Tr Gr
230 - 800 Lt Br Say Si Tr to Some Gr
800 - 1.5 Lt Br Siy Sa Tr Gr

22+300 3.0 Lt of Lt EP EPS

0 - 220 Asph
220 - 1.2 Br F-Co Sa And Gr W Si
1.2 - 1.5 Br Say Si Tr Cl

22+300 1.5 Lt of Lt EP MSH

0 - 220 Asph
220 - 1.0 Br F-Co Sa And Gr Some Si*
1.0 - 1.5 Br F Say Si Tr Cl
* % Passing 26.5 mm = 100
19 mm = 99
4.75 mm = 74
1.18 mm = 56
300 μm = 39
75 μm = 17
MWD = 2.33 t/m3
MDD = 2.19 t/m3
W_{opt} = 7%
NOT Accep Gran "A" or "B"

22+300 0.3 Rt of Lt EP

0 - 380 Asph
380 - 650 Br F-Co Sa And Gr W Si w = 6%
650 - 1.5 Br Mott Dk Br F Say Si w = 15%

N-W RAMP

Datum: Proposed Rt EP

9+980.12 2.5 Lt of Rt EP

0 - 1.3 Br F-Med Sa And Gr Tr Si OCC Cob
1.3 - 1.5 Br Sly Sa Some Gr OCC Cob

10+030.12 10.3 Rt of Rt EP

0 - 260 Dk Br Say Si Tps
260 - 1.5 Lt Br Siy Sa Tr Gr w = 11%

10+080.12 2.5 Lt of Rt EP

0 - 600 Dk Br Say Si Tps Tr Gr Tr Cob Tr Wood
600 - 1.5 Lt Br Siy Sa Tr Gr

10+130.15 12.9 Lt of Rt EP

0 - 260 Dk Br Say Si Tps
260 - 1.5 Lt Br Siy Sa

10+180.17 2.5 Lt of Rt EP

0 - 180 Dk Br Say Si Tps Tr Gr Tr Cob
180 - 1.5 Lt Br Siy Sa Tr Gr w = 9%

10+230.20 12.1 Rt of Rt EP

0 - 280 Dk Br Say Si Tps Tr Gr
280 - 1.2 Br Siy Sa Tr Gr
1.2 - 1.5 Lt Br F-Med Sa And Gr OCC Cob

10+280.23 2.5 Lt of Rt EP

0 - 180 Dk Br Say Si Tps Tr Gr Tr Cob
180 - 1.2 Br Siy Sa Tr Gr
1.2 - 1.5 Lt Br F-Med Sa Tr Si Some Gr

10+330.22 9.8 Lt of Rt EP

0 - 200 Dk Br Say Si Tps
200 - 1.5 Lt Br Siy Sa Tr to Some Gr w = 6%

10+380.23 2.5 Lt of Rt EP

0 - 230 Dk Br Say Si Tps
230 - 1.5 Br Say Si Tr Gr

10+430.24 6.7 Rt of Rt EP

0 - 450 Dk Br Say Si Tps
450 - 700 Lt Br Say Si
700 - 1.5 Lt Br Siy Sa Tr Gr

10+480.22 2.5 Lt of Rt EP

0 - 250 Dk Br Say Si Tps
250 - 1.5 Br Say Si Tr Gr w = 16%

10+530.26 9.8 Lt of Rt EP

0 - 300 Dk Br Say Si Tps Tr Gr
300 - 650 Br Say Si
650 - 1.5 Lt Br Siy Sa Tr Gr

10+580.22 1.0 Lt of Rt EP

0 - 150 Dk Br Say Si Tps Tr Gr
150 - 1.5 Lt Br Siy Sa Tr Gr OCC Cob w = 10%

10+630.22 8.3 Rt of Rt EP

0 - 200 Dk Br Say Si Tps
200 - 600 Lt Br Siy Sa
600 - 1.5 Br Cly Si Tr Gr w = 20%

10+680.22 2.5 Lt of Rt EP

0 - 300 Dk Br Siy Sa W Gr Tr Tps
300 - 1.5 Lt Br Siy Sa Tr Gr

10+730.22 6.6 Rt of Rt EP

0 - 50 Dk Br Say Si Tps
50 - 1.5 Lt Br Siy Sa Tr Gr

10+740.22 11.0 Rt of Rt EP
(Culvert)

0 - 50 Tps
50 - 600 Br Siy Sa Tr Gr
600 - 1.2 Lt Br Siy Sa OCC Cob
1.2 - 1.3 Gry Siy Sa
1.3 - 2.1 Gry Sa Some Si Tr Cl

S-W RAMP

Datum: Proposed EP

10+010 7.5 Lt of Rt EP

0 - 175 Dk Br Say Si Tps Tr Gr
175 - 1.5 Lt Br Siy Sa Tr Gr OCC Cob

10+056.21 6.6 Rt of Rt EP

0 - 300 Dk Br Say Si Tps
300 - 1.5 Lt Br F-Med Sa Tr Si

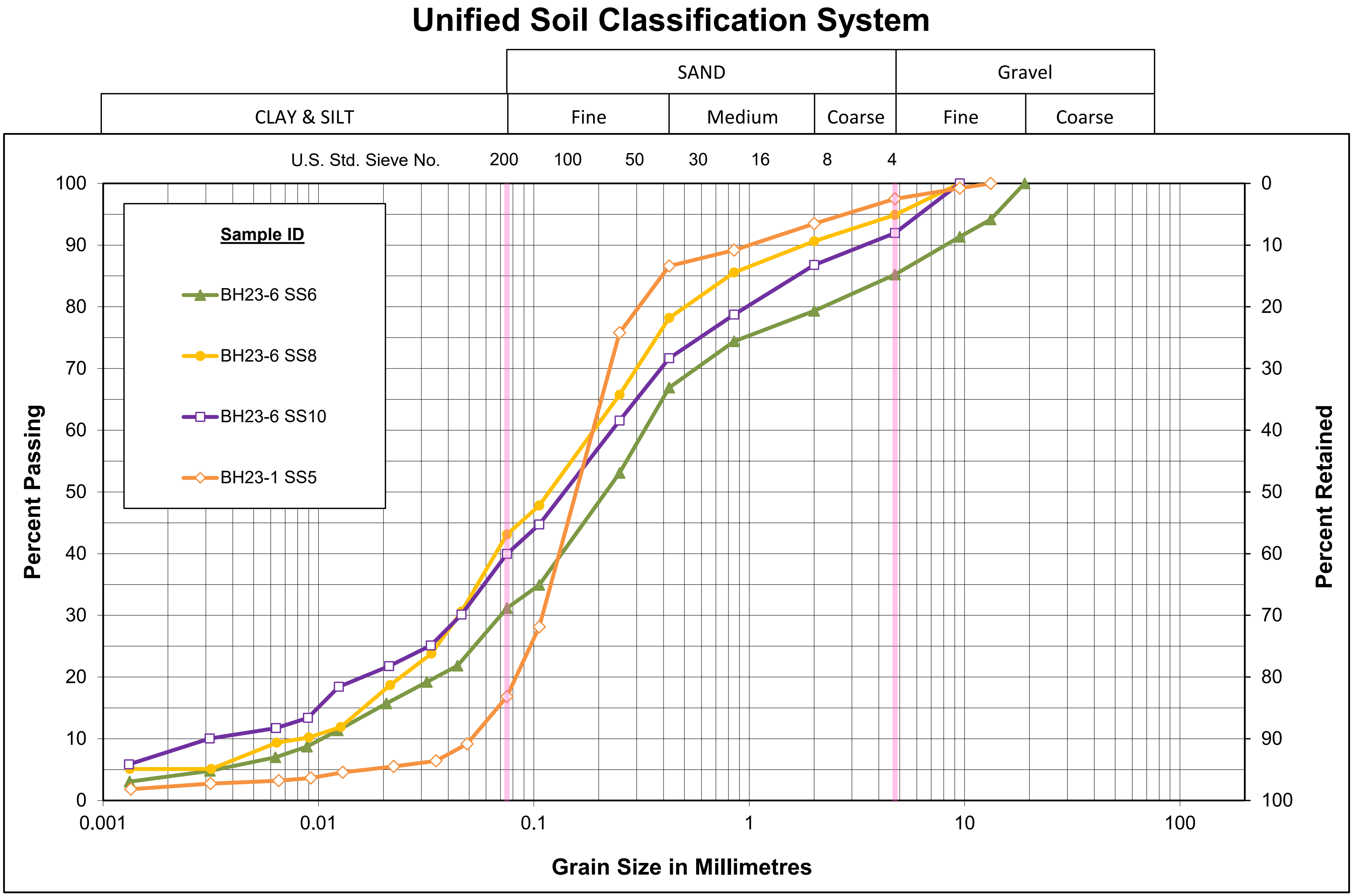
10+105.43 2.2 Lt of Rt EP

0 - 150 Asph
150 - 320 Br F-Med Sa And Gr Tr Si
320 - 750 Br F-Med Sa Tr Si Tr Gr
750 - 1.2 Br Say Si Some Gr
1.2 - 1.5 Dk Br Say Si Tps w = 16%
1.5 - 2.0 Red-Br Siy Sa
2.0 - 2.3 Lt Br F-Med Sa Tr Si

REVISED BY: G. D.
MODIFIED: 2004/01/19 6:32:34
DRAWN BY: D. CAMPBELL

APPENDIX C

C.1 LABORATORY TEST RESULTS



Stantec

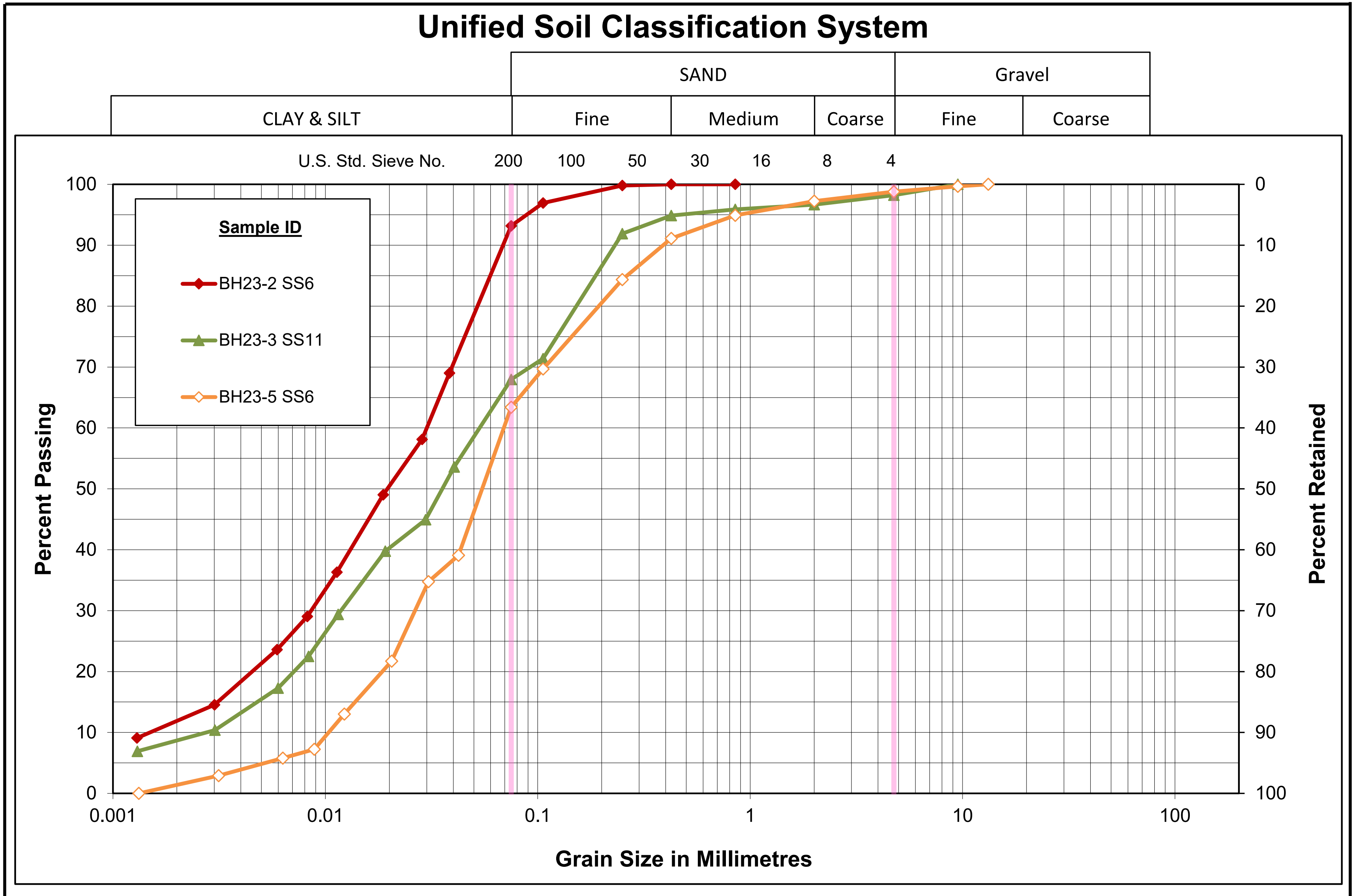
GRAIN SIZE DISTRIBUTION

UPPER SILTY SAND TO SAND (SM)

HWY 401 Improvements, Stage 4A, Muskeg Subgrade

Figure No. C1

Project No. 165000897



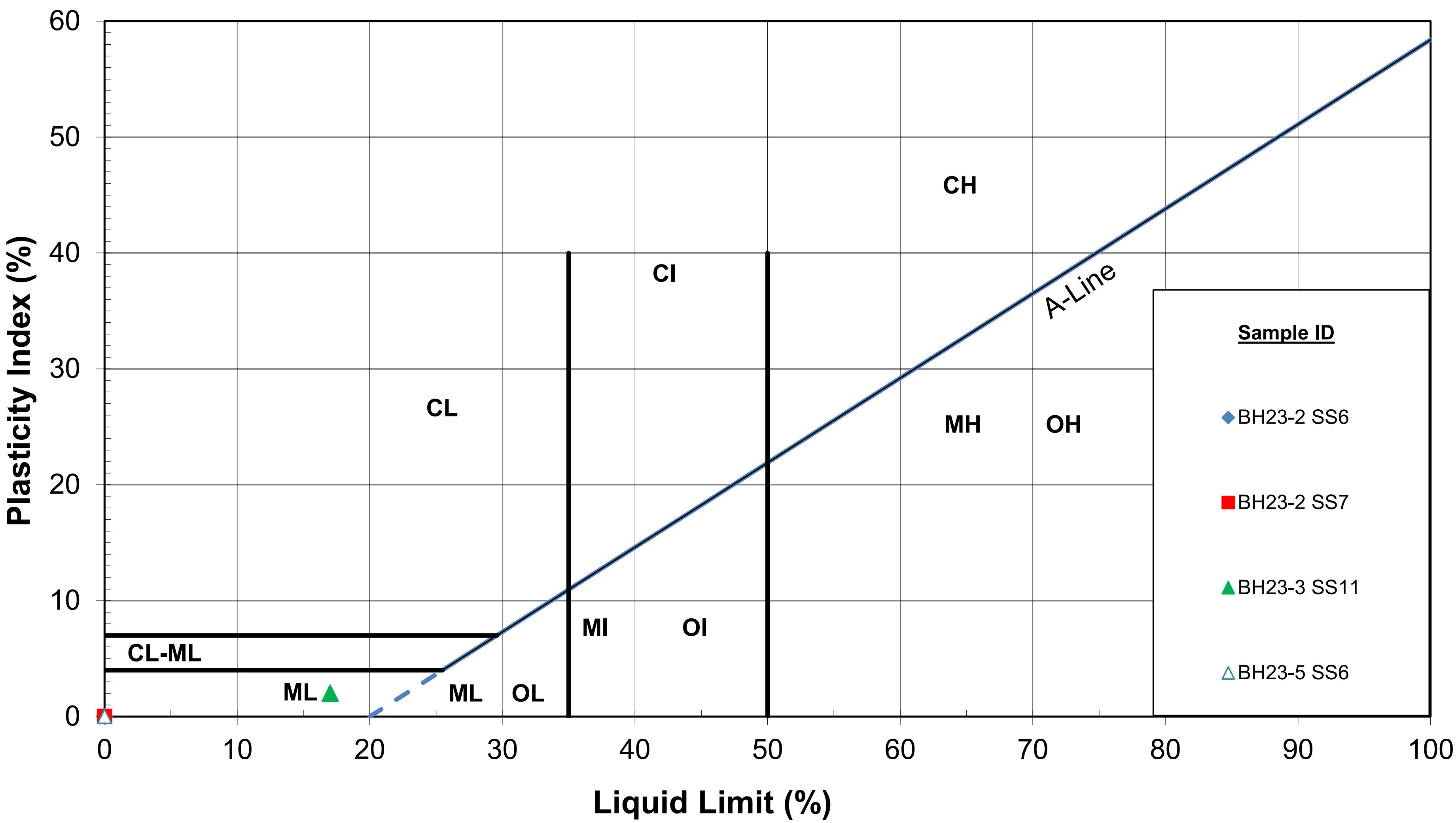
GRAIN SIZE DISTRIBUTION

SILT TO SANDY SILT (ML)

HWY 401 Improvements, Stage 4A, Muskeg Subgrade

Figure No. C2

Project No. 165000897



Stantec

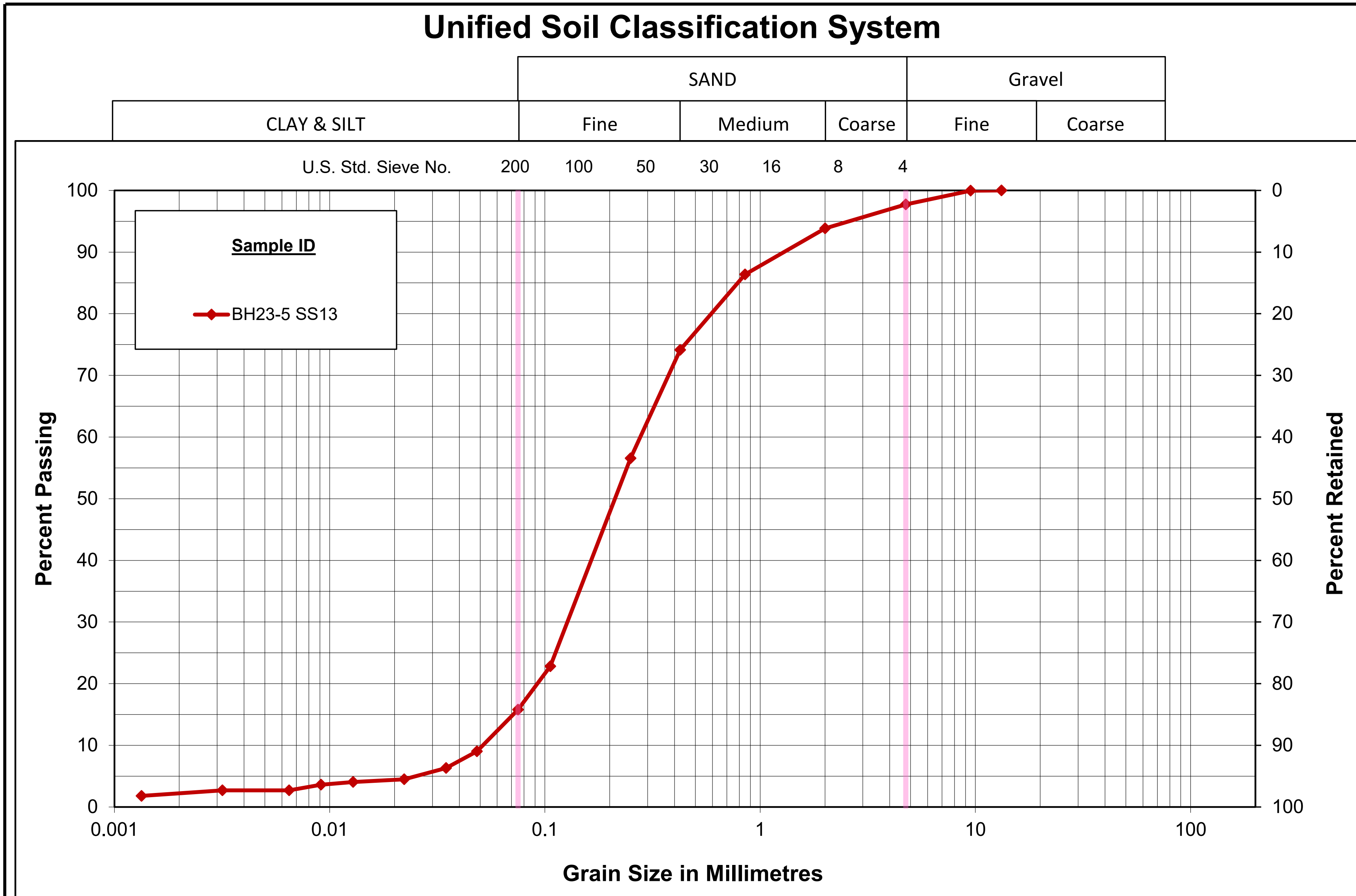
HWY 401 Improvements, Stage 4A, Muskeg Subgrade

SILT TO SANDY SILT (ML)

PLASTICITY CHART

Figure No. C3

Project No. 165000897



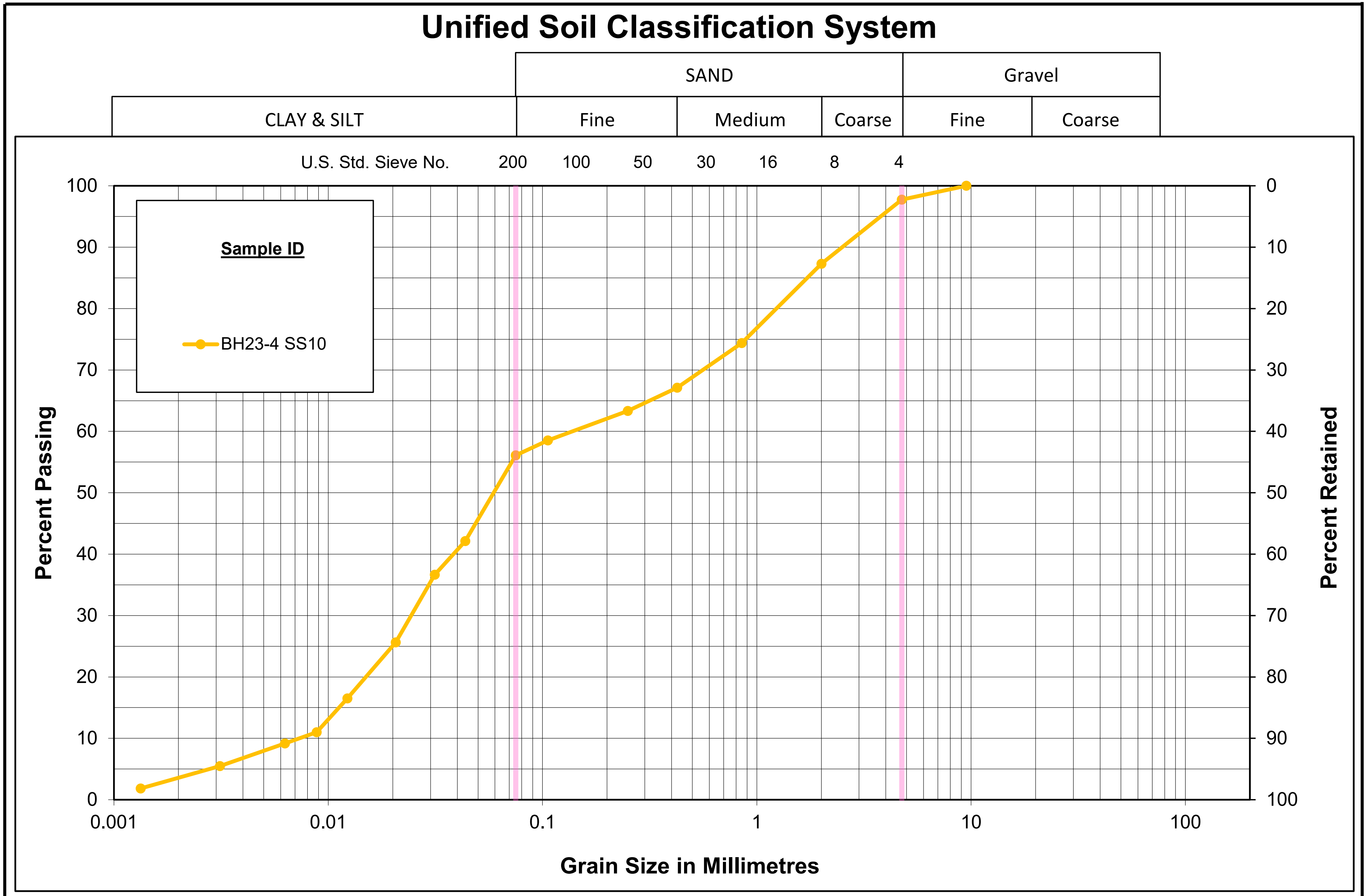
GRAIN SIZE DISTRIBUTION

LOWER SILTY SAND TO SAND (SM)

HWY 401 Improvements, Stage 4A, Muskeg Subgrade

Figure No. C4

Project No. 165000897



Stantec

GRAIN SIZE DISTRIBUTION

SANDY CLAY (CH)

HWY 401 Improvements, Stage 4A, Muskeg Subgrade

Figure No. C5

Project No. 165000897

Stantec

2781 Lancaster Rd.
Ottawa ON, K1B 1A7

Project:	Hwy 401 Cambridge
Project No.:	165000897
Date Sampled:	March 29, 2023
Sampled From:	BH23-3, ST7
Date Tested:	May 5, 2023
Tested By:	Daniel Boateng
Max. Particle Size:	2 mm

Specific Gravity
LS-705

Test Data

Sample No.	BH23-3, ST7	BH23-3, ST7	BH23-3, ST7
Pycnometer Reference No.	1	2	3
Mass of Pycnometer (m_f)	186.62	175.94	169.79
Mass of Dry Specimen + Pycnometer (m_s)	205.66	195.15	189.01
Mass of Dry Soil ($m_s - m_f = m_o$)	19.04	19.21	19.22
Mass of Pycnometer + Water (m_a)	684.89	674.35	667.92
Mass of Pynometer + Specimen + Water (m_b)	691.97	681.34	675.04
Mass of Water Displaced = $[(m_a + m_o) - m_b]$	11.96	12.22	12.10
Temperature of the Content (T_x)	23.00	23.00	23.00
Specific Gravity $G = \frac{m_o}{[m_o + (m_a - m_b)]}$	1.592	1.572	1.588
Mean Specific Gravity at Temperature T_x, $G_{avg} = (G_1 + G_2 + G_3)/3$			1.584
Specific Gravity at 20° C, $G_s = K\,(G_{avg})$ 1.584 x 0.9993			1.583

Removal of entrapped air by: a) Vacuum ☐ b) Boiling ☑

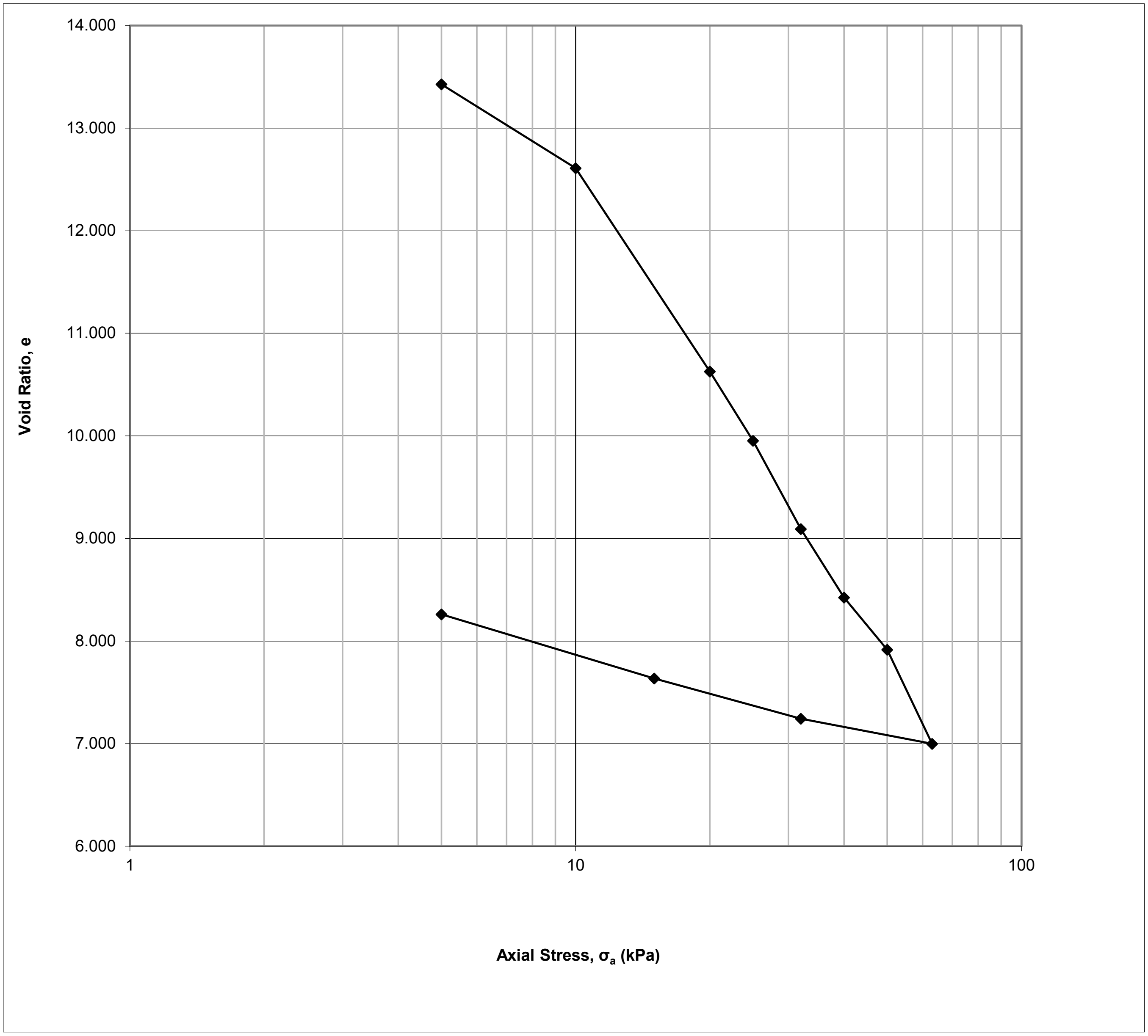
Comments:

Reviewed By: Ramin Ghassemi

Date: 2023/05/11

One-Dimensional Consolidation Properties of Soils Using Incremental Loading
ASTM D2435/D2435M - 11(2020)

Project	**Hwy 401 Cambridge**
Project No.	**165000897**
Borehole No.	**BH23-3**
Sample No.	**ST7**
Sample Depth	**4.6-5.2 m**



Filename: V:\01216\active\other_pc_projects\165000897\ Checked by: D. Boateng Date: May 9, 2023

Date: May 9, 2023 Approved by: R. Ghassemi Date: May 9, 2023

Stantec Consulting Ltd.

One-Dimensional Consolidation Test using Incremental Loading

ASTM D2435/D2435M - 11(2020)

Specimen Details

Project Name	Hwy 401 Cambridge
Project Location	Cambridge, ON
Borehole	BH23-3
Sample No.	ST7
Depth	4.6-5.2 m
Sample Date	March 29, 2023
Test Number	One
Technician Name	Daniel Boateng

Soil Description & Classification

Very strongly decomposed peat that, when squeezed, releases through the fingers about two-thirds of the peat - H8

Specific Gravity of Solids		1.583
Average water content of trimmings	%	974.37

Additional Notes (information source, occurence and size of large isolated particles etc.)

Initial Specimen Conditions

Height	mm	20.00
Diameter	mm	50.00
Area	mm^2	1963
Volume	mm^3	39270
Mass	g	40.62
Dry Mass	g	3.90
Density	Mg/m^3	1.034
Dry Density	Mg/m^3	0.099
Water Content	%	941.54
Degree of Saturation	%	99.8
Height of Solids	mm	1.25
Initial Void Ratio		14.940

Final Specimen Conditions

Water Content	%	580.51
Final Void Ratio		8.259
Final Height	mm	11.62

Filename: V:\01216\active\other_pc_projects\165000897\03_data\Lab Testing\2023\consolidatic Checked by: D. Boateng Date: May 9, 2023

Date: May 9, 2023 Approved by: R. Ghassemi Date: May 9, 2023

Stantec

Stantec Consulting Ltd.

One-Dimensional Consolidation Test using Incremental Loading

ASTM D2435/D2435M - 11(2020)

Specimen Details

Project Name	Hwy 401 Cambridge
Project Location	Cambridge, ON
Borehole	BH23-3
Sample No.	ST7
Depth	4.6-5.2 m
Sample Date	March 29, 2023
Test Number	One
Technician Name	Daniel Boateng

Test Procedure

Date Started	April 20, 2023
Date Finished	May 1, 2023
Machine Number	Frame E
Cell Number	E
Ring Number	E
Trimming Procedure	Turntable/cutting ring
Moisture Condition	Inundated
Axial Stress at Inundation kPa	5
Water Used	Deaired tap water
Test Method	A
Interpretation Procedure for c_v	2

All Departures from Outlined ASTM D2435/D2435M-11 (2020) Procedure

Calculations

Load Increment	Increment Duration (min)	Axial Stress σ_a (kPa)	Corrected Deformation ΔH (mm)	Specimen Height H (mm)	Axial Strain ε_a (%)	Void Ratio e
Seating	0.0	0	0.0000	20.0000	0.00	14.940
1	1440.0	5	1.8989	18.1011	9.49	13.426
2	1440.0	10	2.9248	17.0752	14.62	12.609
3	1440.0	20	5.4113	14.5887	27.06	10.627
4	1440.0	25	6.2588	13.7412	31.29	9.951
5	1440.0	32	7.3364	12.6636	36.68	9.093
6	1440.0	40	8.1753	11.8247	40.88	8.424
7	1440.0	50	8.8131	11.1869	44.07	7.916
8	1440.0	63	9.9635	10.0365	49.82	6.999
9	1440.0	32	9.6583	10.3417	48.29	7.242
10	1440.0	15	9.1659	10.8341	45.83	7.635
11	1440.0	5	8.3819	11.6181	41.91	8.259

Stantec

Stantec Consulting Ltd.

One-Dimensional Consolidation Test using Incremental Loading

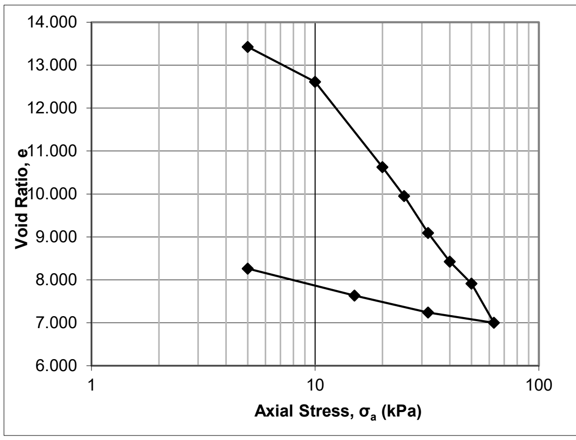
ASTM D2435/D2435M - 11(2020)

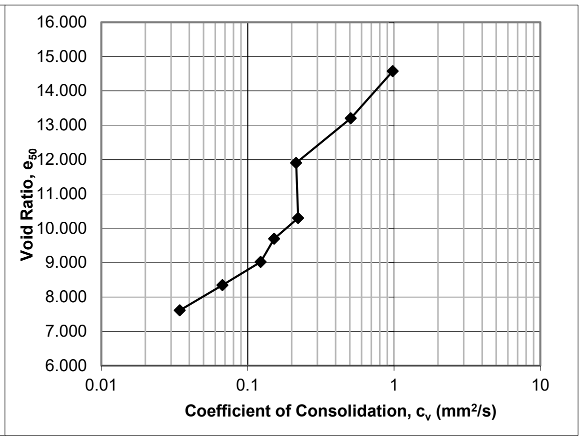
Specimen Details

Job Ref.	Hwy 401 Cambridge
Job Location	Cambridge, ON
Borehole	BH23-3
Sample No.	ST7
Depth	4.6-5.2 m
Sample Date	March 29, 2023
Test Number	One
Technician Name	Daniel Boateng

Calculations

		Calculated using Interpretation Procedure 2				Interpretation Procedure 1		Interpretation Procedure 2	
Load Increment	Axial Stress $\sigma_{a,\ average}$ kPa	Corrected Deformation ΔH_{50} mm	Specimen Height H_{50} mm	Axial Strain $\varepsilon_{a,50}$ %	Void Ratio e_{50}	Time t_{50} sec	Coeff. Consol. c_v mm^2/s	Time t_{90} sec	Coeff. Consol. c_v mm^2/s
Seating	0								
1	3	0.4540	19.5460	2.27	14.578			82	9.83E-01
2	8	2.1738	17.8262	10.87	13.207			133	5.08E-01
3	15	3.8081	16.1919	19.04	11.905			259	2.15E-01
4	23	5.8165	14.1835	29.08	10.304			192	2.22E-01
5	29	6.5757	13.4243	32.88	9.699			252	1.52E-01
6	36	7.4214	12.5786	37.11	9.025			274	1.23E-01
7	45	8.2677	11.7323	41.34	8.350			433	6.75E-02
8	57	9.1906	10.8094	45.95	7.615			719	3.44E-02
9	48	9.8602	10.1398	49.30	7.081				
10	24	9.5165	10.4835	47.58	7.355				
11	10	8.9676	11.0324	44.84	7.793				





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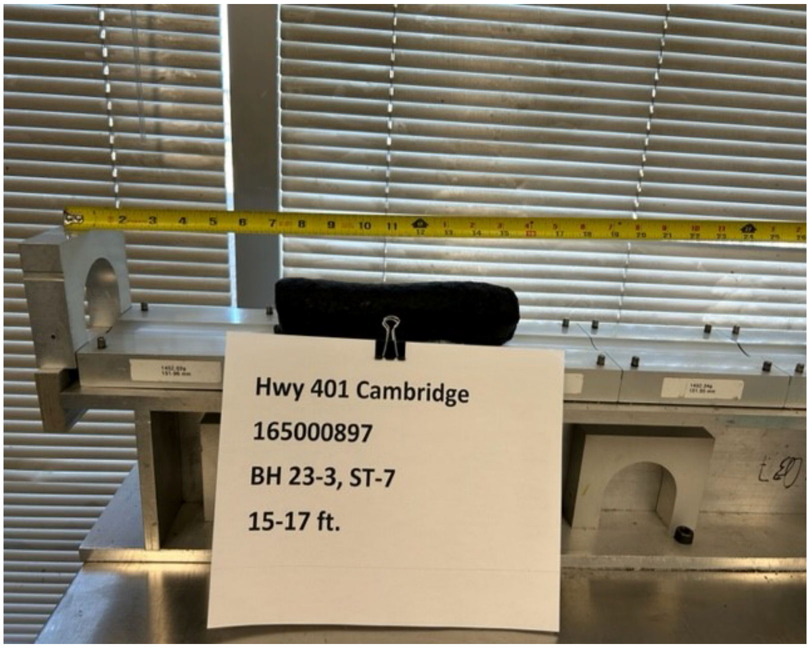
Date: May 9, 2023
Checked by: D. Boateng Date: May 9, 2023
Approved by: R. Ghassemi Date: May 9, 2023

Stantec	Project No.: 165000897 Project Name: Hwy 401 Cambridge	Photo Log



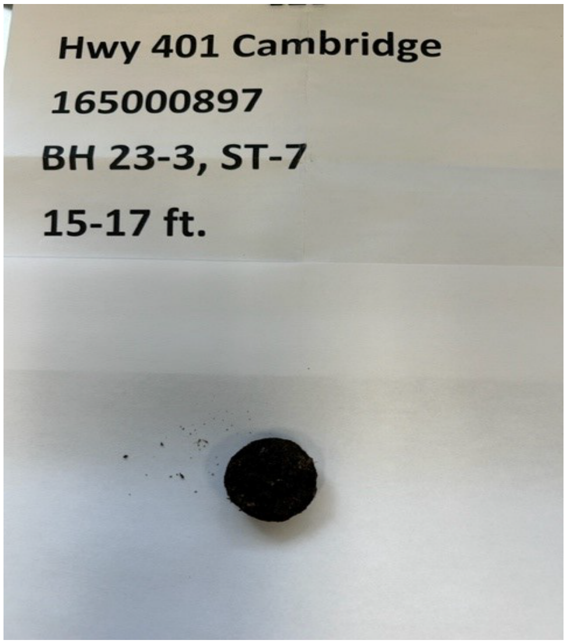


Photo No.: 1 &2	Borehole: BH 23-3 ST 7	Depth: 4.6-5.2 m

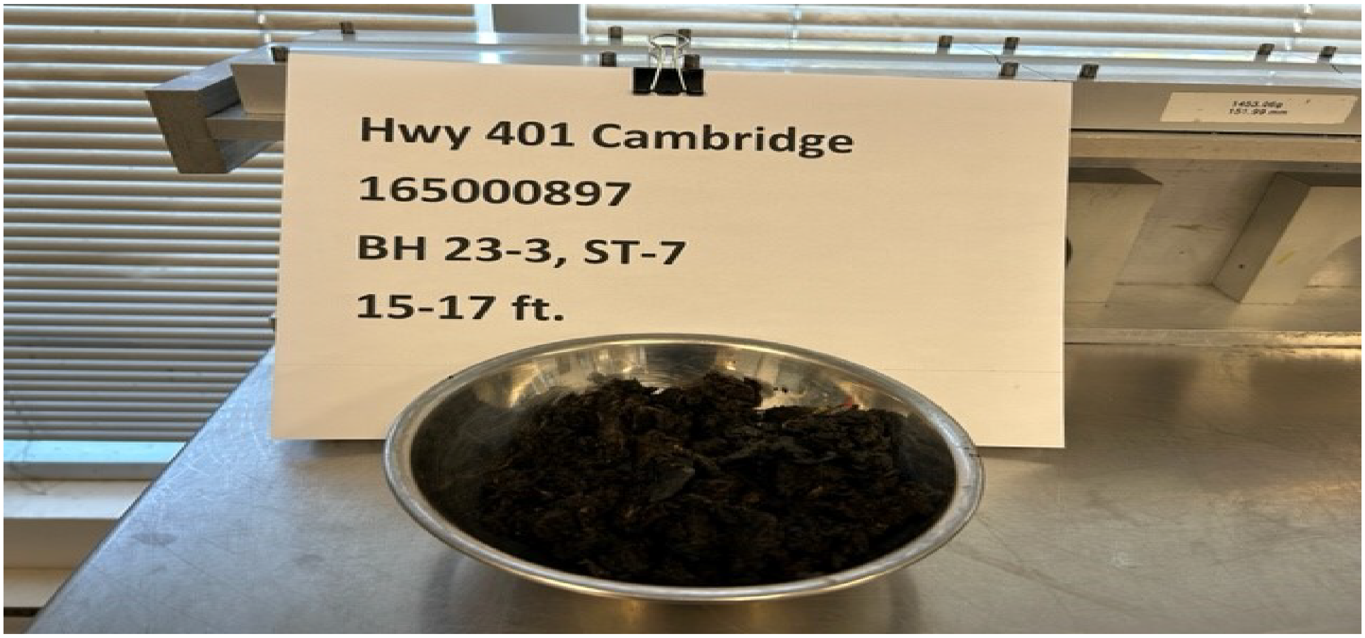
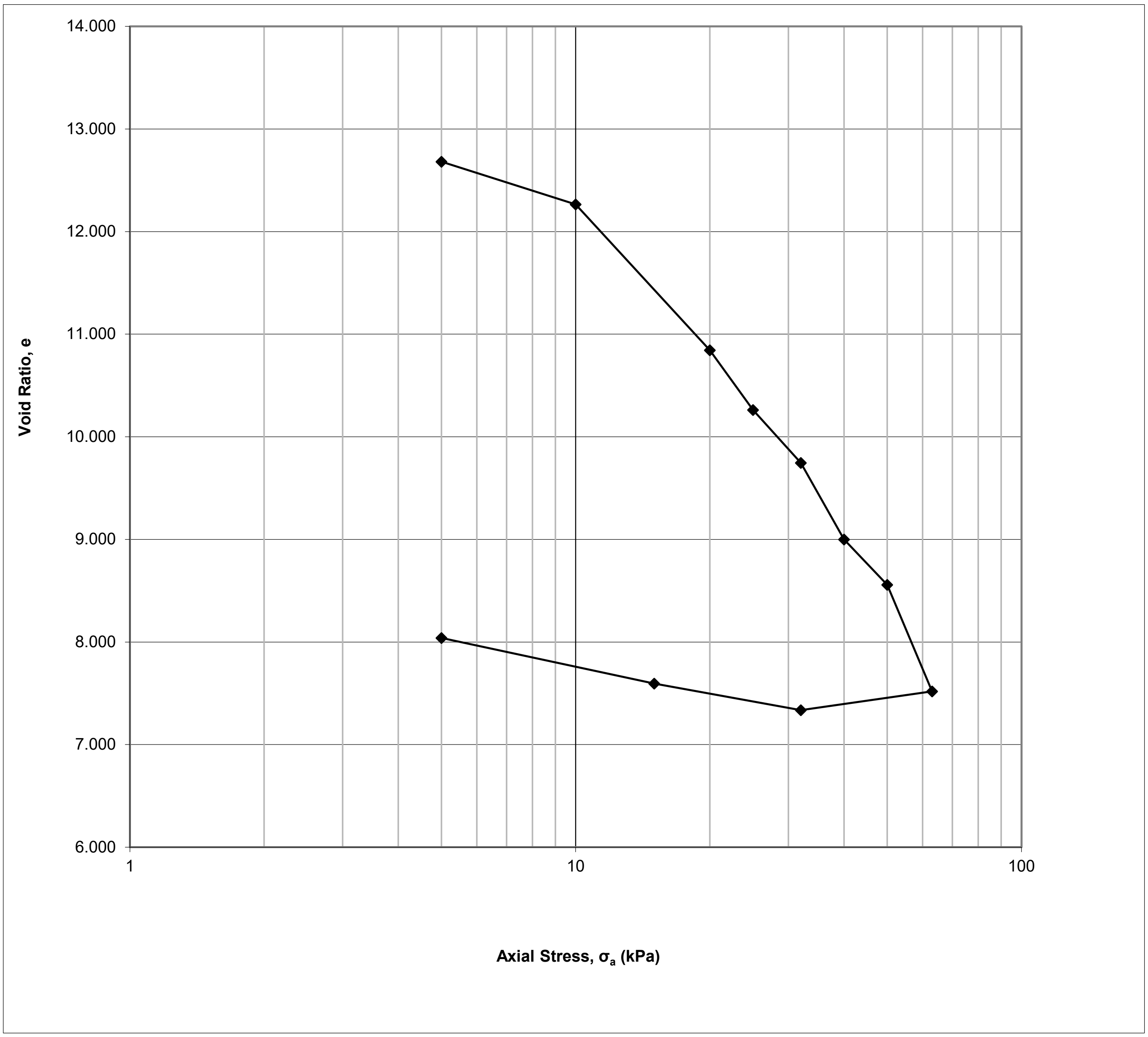


Photo No.: 3	Borehole: BH 23-3 ST 7	Depth: 4.6-5.2 m

One-Dimensional Consolidation Properties of Soils Using Incremental Loading

ASTM D2435/D2435M - 11(2020)

Project	**Hwy 401 Cambridge**
Project No.	**165000897**
Borehole No.	**BH23-4**
Sample No.	**ST8**
Sample Depth	**5.3-5.8 m**



Stantec Consulting Ltd.

D. Boateng Date: May 9, 2023
R. Ghassemi Date: May 9, 2023
Filename: V:\01216\active\other_pc_projects\165000897\ Checked by: Approved by:
Date: May 9, 2023

One-Dimensional Consolidation Test using Incremental Loading

ASTM D2435/D2435M - 11(2020)

Specimen Details

Project Name	Hwy 401 Cambridge
Project Location	Cambridge, ON
Borehole	BH23-4
Sample No.	ST8
Depth	5.3-5.8 m
Sample Date	March 29, 2023
Test Number	Two
Technician Name	Daniel Boateng

Soil Description & Classification

Very strongly decomposed peat that, when squeezed, releases through the fingers about two-thirds of the peat - H8

Specific Gravity of Solids	1.583
Average water content of trimmings %	899.9

Additional Notes (information source, occurence and size of large isolated particles etc.)

Initial Specimen Conditions

Height	mm	20.00
Diameter	mm	50.00
Area	mm^2	1963
Volume	mm^3	39270
Mass	g	41.42
Dry Mass	g	4.32
Density	Mg/m^3	1.055
Dry Density	Mg/m^3	0.110
Water Content	%	858.80
Degree of Saturation	%	101.5
Height of Solids	mm	1.39
Initial Void Ratio		13.390

Final Specimen Conditions

Water Content	%	603.47
Final Void Ratio		8.040
Final Height	mm	12.56

Stantec Consulting Ltd.

One-Dimensional Consolidation Test using Incremental Loading

ASTM D2435/D2435M - 11(2020)

Specimen Details

Project Name	Hwy 401 Cambridge
Project Location	Cambridge, ON
Borehole	BH23-4
Sample No.	ST8
Depth	5.3-5.8 m
Sample Date	March 29, 2023
Test Number	Two
Technician Name	Daniel Boateng

Test Procedure

Date Started	April 20, 2023
Date Finished	May 1, 2023
Machine Number	Frame F
Cell Number	F
Ring Number	F
Trimming Procedure	Turntable/cutting ring
Moisture Condition	Inundated
Axial Stress at Inundation kPa	5
Water Used	Deaired tap water
Test Method	A
Interpretation Procedure for c_v	2

All Departures from Outlined ASTM D2435/D2435M-11 (2020) Procedure

Calculations

Load Increment	Increment Duration (min)	Axial Stress σ_a (kPa)	Corrected Deformation ΔH (mm)	Specimen Height H (mm)	Axial Strain ε_a (%)	Void Ratio e
Seating	0.0	0	0.0000	20.0000	0.00	13.390
1	1440.0	5	0.8224	19.1776	4.93	12.681
2	1440.0	10	1.2371	18.7629	7.82	12.264
3	1440.0	20	2.5920	17.4080	17.69	10.844
4	1440.0	25	3.7014	16.2986	21.73	10.263
5	1440.0	32	4.5447	15.4553	25.33	9.745
6	1440.0	40	5.4447	14.5553	30.52	8.998
7	1440.0	50	6.2733	13.7267	33.58	8.558
8	1440.0	63	7.2362	12.7638	40.80	7.519
9	1440.0	32	8.4697	11.5303	42.07	7.336
10	1440.0	15	8.2574	11.7426	40.28	7.594
11	1440.0	5	7.7255	12.2745	37.18	8.040

Checked by: D. Boateng Date: May 9, 2023
Approved by: R. Ghassemi Date: May 9, 2023
Filename: V:\01216\active\other_pc_projects\165000897\03_d
Date: May 9, 2023

Stantec Consulting Ltd.

One-Dimensional Consolidation Test using Incremental Loading

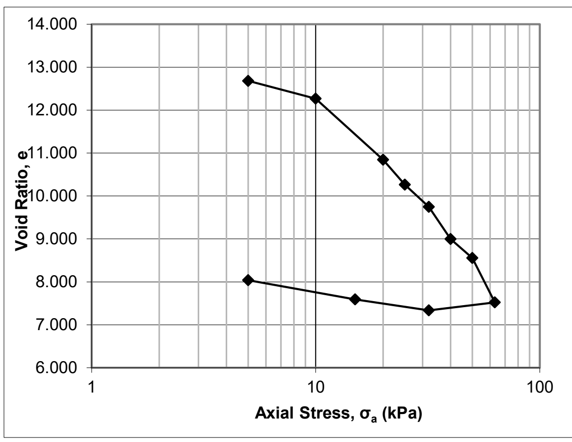
ASTM D2435/D2435M - 11(2020)

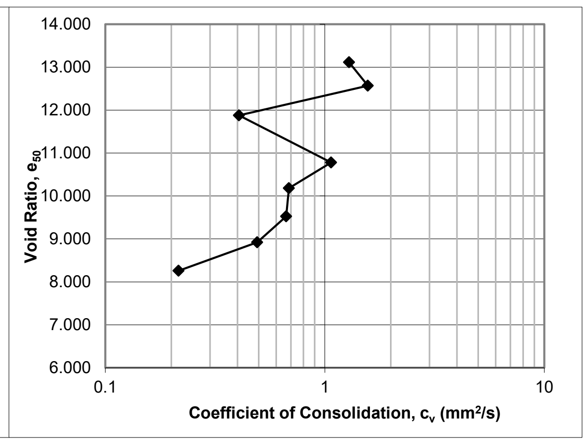
Specimen Details

Job Ref.	Hwy 401 Cambridge
Job Location	Cambridge, ON
Borehole	BH23-4
Sample No.	ST8
Depth	5.3-5.8 m
Sample Date	March 29, 2023
Test Number	Two
Technician Name	Daniel Boateng

Calculations

		Calculated using Interpretation Procedure 2				Interpretation Procedure 1		Interpretation Procedure 2	
Load Increment	Axial Stress $\sigma_{a,\ average}$ kPa	Corrected Deformation ΔH_{50} mm	Specimen Height H_{50} mm	Axial Strain $\varepsilon_{a,50}$ %	Void Ratio e_{50}	Time t_{50} sec	Coeff. Consol. c_v mm^2/s	Time t_{90} sec	Coeff. Consol. c_v mm^2/s
Seating	0								
1	3	0.3868	19.6132	1.93	13.112			63	1.29E+00
2	8	1.1407	18.8593	5.70	12.569			48	1.57E+00
3	15	2.1015	17.8985	10.51	11.878			167	4.07E-01
4	23	3.6301	16.3699	18.15	10.778			53	1.07E+00
5	29	4.4619	15.5381	22.31	10.180			75	6.86E-01
6	36	5.3722	14.6278	26.86	9.525			68	6.67E-01
7	45	6.2083	13.7917	31.04	8.923			82	4.93E-01
8	57	7.1316	12.8684	35.66	8.259			163	2.16E-01
9	48	8.4952	11.5048	42.48	7.278			75	3.72E-01
10	24	8.3188	11.6812	41.59	7.405			225	1.28E-01
11	10	7.8755	12.1245	39.38	7.724			790	3.95E-02





Stantec	Project No.: 165000897	Photo Log
	Project Name: Hwy 401 Cambridge	

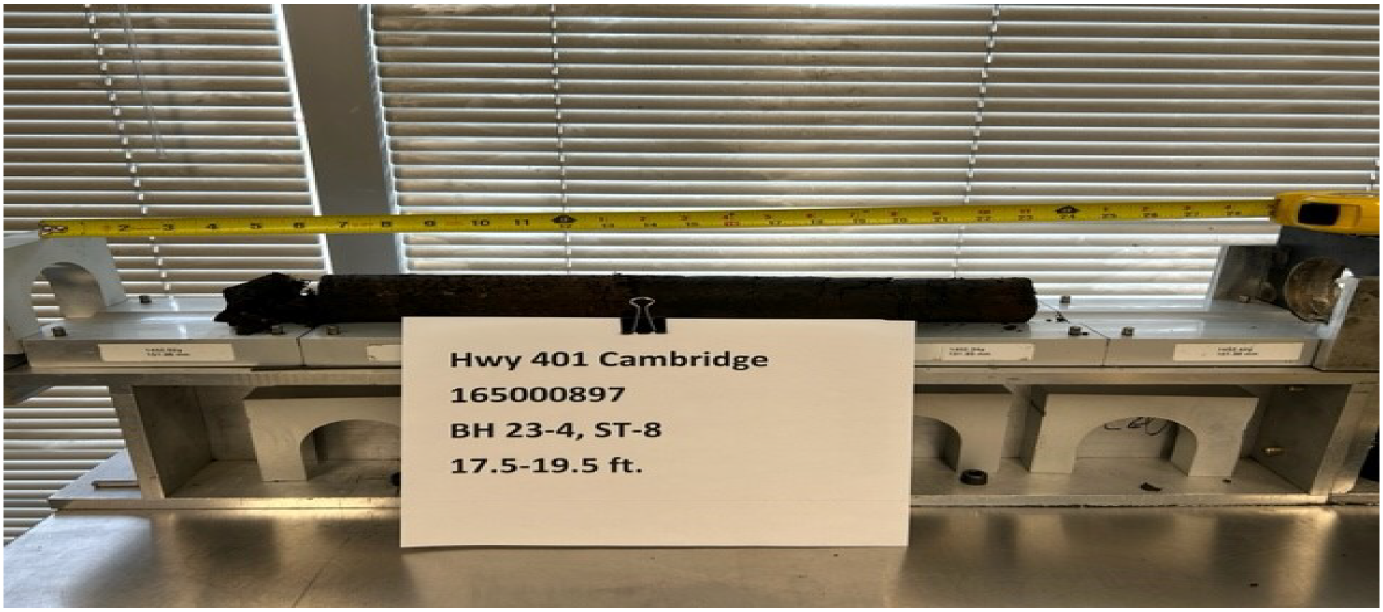


Photo No.: 1	Borehole: BH 23-4 ST 8	Depth: 5.3-5.8 m

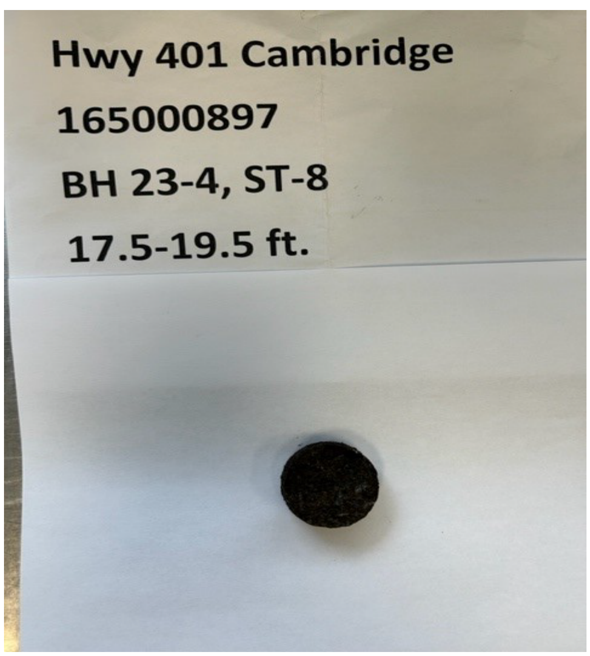


Photo No.: 2	Borehole: BH 23-4 ST 8	Depth: 5.3-5.8 m

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Certificate of Analysis

Stantec Consulting Ltd. (Ottawa)

1331 Clyde Avenue Suite 400
Ottawa, ON K2C 3G4
Attn: Brian Prevost

Client PO: 165000897
Project: 165000897
Custody:

Report Date: 9-May-2023
Order Date: 28-Apr-2023

Order #: 2317500

This Certificate of Analysis contains analytical data applicable to the following samples as submitted :

Paracel ID	Client ID
2317500-01	BH23-1, SS2, 2 ½ -4 ½ ft
2317500-02	BH23-2, SS1, 0-2 ft
2317500-03	BH23-2, SS2, 2 ½ -4 ½ ft
2317500-04	BH23-2, SS3, 5-7 ft
2317500-05	BH23-2, SS7
2317500-06	BH23-3, SS2, 2-4 ft
2317500-07	BH23-3, SS3, 5-7 ft
2317500-08	BH23-3, SS5, 10-12 ft
2317500-09	BH23-3, ST7, 15-17 ft
2317500-10	BH23-3, SS8, 17 ½ -19 ½ ft
2317500-11	BH23-3, SS10A, 22 ½ -24 ½ ft
2317500-12	BH23-3, SS13
2317500-13	BH23-4, SS2, 2 ½ -4 ½ ft
2317500-14	BH23-4, SS4, 7 ½ -9 ½ ft
2317500-15	BH23-4, SS6, 12 ½ -14 ½ ft
2317500-16	BH23-4, SS7, 15-17 ft
2317500-17	BH23-4, ST8, 17 ½ -19 ½ ft
2317500-18	BH23-4, SS9A, 20-22 ft
2317500-19	BH23-5, SS7B, 15-17 ft

Approved By:

Dale Robertson, BSc
Laboratory Director

Certificate of Analysis

Client: Stantec Consulting Ltd. (Ottawa)

Client PO: 165000897

Report Date: 09-May-2023

Order Date: 28-Apr-2023

Project Description: 165000897

Analysis Summary Table

Analysis	Method Reference/Description	Extraction Date	Analysis Date
Anions	EPA 300.1 - IC, water extraction	4-May-23	5-May-23
Loss on Ignition, 440C	84-045	28-Apr-23	3-May-23
pH, soil	EPA 150.1 - pH probe @ 25 °C, CaCl buffered ext.	2-May-23	2-May-23
Resistivity	EPA 120.1 - probe, water extraction	4-May-23	5-May-23
Solids, %	CWS Tier 1 - Gravimetric	1-May-23	2-May-23

Certificate of Analysis
Client: Stantec Consulting Ltd. (Ottawa)
Client PO: 165000897

Report Date: 09-May-2023
Order Date: 28-Apr-2023
Project Description: 165000897

	Client ID:	BH23-1, SS2, 2 ½ -4 ½ ft	BH23-2, SS1, 0-2 ft	BH23-2, SS2, 2 ½ -4 ½ ft	BH23-2, SS3, 5-7 ft
	Sample Date:	23-Mar-23 09:00	23-Mar-23 09:00	23-Mar-23 09:00	23-Mar-23 09:00
	Sample ID:	2317500-01	2317500-02	2317500-03	2317500-04
	MDL/Units	Soil	Soil	Soil	Soil
General Inorganics					
Loss on Ignition, 440C	0.1 % by Wt.	3.4 [2]	74.8 [2]	-	75.7 [2]
pH	0.05 pH Units	-	-	6.94 [2]	-

	Client ID:	BH23-2, SS7	BH23-3, SS2, 2-4 ft	BH23-3, SS3, 5-7 ft	BH23-3, SS5, 10-12 ft
	Sample Date:	23-Mar-23 09:00	24-Mar-23 09:00	24-Mar-23 09:00	24-Mar-23 09:00
	Sample ID:	2317500-05	2317500-06	2317500-07	2317500-08
	MDL/Units	Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	85.4	-	-	-
General Inorganics					
Loss on Ignition, 440C	0.1 % by Wt.	-	61.7 [2]	-	73.2 [2]
pH	0.05 pH Units	7.61 [2]	-	6.95 [2]	-
Resistivity	0.1 Ohm.m	29.9	-	-	-
Anions					
Chloride	10 ug/g dry	91 [2]	-	-	-
Sulphate	10 ug/g dry	63 [2]	-	-	-

	Client ID:	BH23-3, ST7, 15-17 ft	BH23-3, SS8, 17 ½ -19 ½ ft	BH23-3, SS10A, 22 ½ -24 ½ ft	BH23-3, SS13
	Sample Date:	24-Mar-23 09:00	24-Mar-23 09:00	27-Mar-23 09:00	27-Mar-23 09:00
	Sample ID:	2317500-09	2317500-10	2317500-11	2317500-12
	MDL/Units	Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	-	-	-	74.7
General Inorganics					
Loss on Ignition, 440C	0.1 % by Wt.	81.9 [2]	82.4 [2]	70.2 [2]	-
pH	0.05 pH Units	-	-	-	7.47 [2]
Resistivity	0.1 Ohm.m	-	-	-	19.7
Anions					
Chloride	10 ug/g dry	-	-	-	114 [2]
Sulphate	10 ug/g dry	-	-	-	165 [2]

Certificate of Analysis

Client: Stantec Consulting Ltd. (Ottawa)

Client PO: 165000897

Report Date: 09-May-2023

Order Date: 28-Apr-2023

Project Description: 165000897

	Client ID:	BH23-4, SS2, 2 ½ -4 ½ ft	BH23-4, SS4, 7 ½ -9 ½ ft	BH23-4, SS6, 12 ½ -14 ½ ft	BH23-4, SS7, 15-17 ft
	Sample Date:	28-Mar-23 09:00	28-Mar-23 09:00	29-Mar-23 09:00	29-Mar-23 09:00
	Sample ID:	2317500-13	2317500-14	2317500-15	2317500-16
	MDL/Units	Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	-	-	-	8.7
General Inorganics					
Loss on Ignition, 440C	0.1 % by Wt.	55.3 [2]	79.7 [2]	86.5 [2]	-
pH	0.05 pH Units	-	-	-	6.22 [2]
Resistivity	0.1 Ohm.m	-	-	-	7.1 [1]
Anions					
Chloride	10 ug/g dry	-	-	-	7430 [2]
Sulphate	10 ug/g dry	-	-	-	<50 [2]

	Client ID:	BH23-4, ST8, 17 ½ -19 ½ ft	BH23-4, SS9A, 20-22 ft	BH23-5, SS7B, 15-17 ft	-
	Sample Date:	29-Mar-23 09:00	29-Mar-23 09:00	29-Mar-23 09:00	-
	Sample ID:	2317500-17	2317500-18	2317500-19	-
	MDL/Units	Soil	Soil	Soil	-
General Inorganics					
Loss on Ignition, 440C	0.1 % by Wt.	84.8 [2]	70.9 [2]	14.7 [2]	-

Method Quality Control: Blank

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Anions									
Chloride	ND	10	ug/g						
Sulphate	ND	10	ug/g						
General Inorganics									
Loss on Ignition, 440C	ND	0.1	% by Wt.						
Resistivity	ND	0.1	Ohm.m						

Method Quality Control: Duplicate

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Anions									
Chloride	ND	10	ug/g	ND			NC	35	
Sulphate	ND	10	ug/g	ND			NC	35	
General Inorganics									
Loss on Ignition, 440C	4.16	0.1	% by Wt.	3.38			20.7	35	H-01
pH	7.39	0.05	pH Units	7.40			0.1	2.3	
Resistivity	31.5	0.1	Ohm.m	29.9			5.4	20	
Physical Characteristics									
% Solids	86.7	0.1	% by Wt.	89.0			2.6	25	

Method Quality Control: Spike

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Anions									
Chloride	104	10	ug/g	ND	104	82-118			
Sulphate	108	10	ug/g	ND	108	80-120			

Qualifier Notes:

Login Qualifiers :

Container(s) - Labeled improperly/insufficient information - Sample labelled as BH-1, chain of custody reads BH23-1.

Applies to samples: BH23-1, SS2, 2 ½ -4 ½ ft

Container(s) - Labeled improperly/insufficient information - Sample labelled as BH-4, chain of custody reads BH23-4.

Applies to samples: BH23-4, SS4, 7 ½ -9 ½ ft

Sample - One or more parameter received past hold time -

Applies to samples: BH23-1, SS2, 2 ½ -4 ½ ft, BH23-2, SS1, 0-2 ft, BH23-2, SS2, 2 ½ -4 ½ ft, BH23-2, SS3, 5-7 ft, BH23-3, SS2, 2-4 ft, BH23-3, SS3, 5-7 ft, BH23-3, SS5, 10-12 ft, BH23-3, ST7, 15-17 ft, BH23-3, SS8, 17 ½ -19 ½ ft, BH23-3, SS10A, 22 ½ -24 ½ ft, BH23-4, SS2, 2 ½ -4 ½ ft, BH23-4, SS4, 7 ½ -9 ½ ft, BH23-4, SS6, 12 ½ -14 ½ ft, BH23-4, ST8, 17 ½ -19 ½ ft, BH23-4, SS9A, 20-22 ft, BH23-8, SS7B, 15-17 ft

Sample - One or more parameter received past hold time - Chloride, pH, Sulphate

Applies to samples: BH23-2, SS8, BH23-3, SS13, BH23-4, SS7, 15-17 ft

Sample Qualifiers :

1 : Due to the nature of the matrix, sample preparation for this analysis deviated from the Paracel prescribed method.

2 : Holding time had been exceeded upon receipt of the sample at the laboratory or prior to the analysis being requested.

QC Qualifiers :

H-01 Holding time had been exceeded upon receipt of the sample at the laboratory or prior to the analysis being requested.

Sample Data Revisions

None

Work Order Revisions / Comments:

None

Other Report Notes:

n/a: not applicable
ND: Not Detected
MDL: Method Detection Limit
Source Result: Data used as source for matrix and duplicate samples
%REC: Percent recovery.
RPD: Relative percent difference.
NC: Not Calculated

Soil results are reported on a dry weight basis when the units are denoted with 'dry'.
Where %Solids is reported, moisture loss includes the loss of volatile hydrocarbons.

Paracel ID: 2317500

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Chain of Custody (Lab Use Only)

Page _1_ of _2_

Client Name: Stantec Consulting Ltd.	Project Reference: 165000897	TAT: [X] Regular [ ] 3 Day
Contact Name: Brian Prevost	Task #:	[ ] 2 Day [ ] 1 Day
Address: 2781 Lancaster Road., Suite 100 A&B, Ottawa ON, K1B 1A7	PO# 165000897	
	Email Address: Ramin.Ghassemi@Stantec.com	Date Required:
Telephone: (613) 738-6075	brian.prevost@stantec.com	

Criteria: [ ] O. Reg. 153/04 Table __ [ ] O. Reg. 153/11 (Current) Table __ [ ] RSC Filing [ ] O. Reg. 558/00 [ ] PWQO [ ] CCME [ ] SUB (Storm) [ ] SUB (Sanitary) Municipality: ______ [ ] Other: ___

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Paracel Order Number: 2317500

	Sample ID/Location Name	Matrix	Air Volume	# of Containers	Sample Taken Date	Sample Taken Time	ASTM D2974, Organic Matter, Method A	Resistivity	PH	Sulphate & Chloride							
1	BH23-1, SS2, 2½-4½ ft	Soil		1	March 23, 2023	AM	X										
2	BH23-2, SS1, 0-2 ft	Soil		1	March 23, 2023	AM	X										
3	BH23-2, SS2, 2½-4½ ft	Soil		1	March 23, 2023	AM			X								
4	BH23-2, SS3, 5-7 ft	Soil		1	March 23, 2023	AM	X										
5	BH23-2, SS7	Soil		1	March 23, 2023	AM		X	X	X							
6	BH23-3, SS2, 2-4 ft	Soil		1	March 24, 2023	AM	X										
7	BH23-3, SS3, 5-7 ft	Soil		1	March 24, 2023	AM			X								
8	BH23-3, SS5, 10-12 ft	Soil		1	March 24, 2023	AM	X										
9	BH23-3, ST7, 15-17 ft	Soil		1	March 24, 2023	AM	X										
10	BH23-3, SS8, 17½-19½ ft	Soil		1	March 24, 2023	AM	X										

Comments: Temperature at 440 °C +/- 40°C for organic contents

Method of Delivery: Swift

Relinquished By (Print & Sign): Daniel Boaten	Received by Driver/Depot:	Received at Lab: Jyneyami Ohmai	Verified By: Sandra Demcaius
	Date/Time:	Date/Time: Apr 28, 2023 09.27	Date/Time: April 28, 11:04
Date/Time: April 27, 2023	Temperature: ___ °C	Temperature: 23.4 °C	pH Verified [ ] By:

Paracel ID: 2317500

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Chain of Custody
(Lab Use Only)

Client Name: Stantec Consulting Ltd.	Project Reference: 165000897	TAT: [X] Regular	[ ] 3 Day
Contact Name: Brian Prevost	Task #:	[ ] 2 Day	[ ] 1 Day
Address: 2781 Lancaster Road., Suite 100 A&B, Ottawa ON. K1B-1A7	PO# 165000897	Date Required:	
Telephone: (613) 738-6075	Email Address: Ramin.Ghassemi@Stantec.com brian.prevost@stantec.com		

Criteria: [ ] O. Reg. 153/04 Table __ [ ] O. Reg. 153/11 (Current) Table __ [ ] RSC Filing [ ] O. Reg. 558/00 [ ] PWQO [ ] CCME [ ] SUB (Storm) [ ] SUB (Sanitary) Municipality:________ [ ] Other: ____

Matrix Type: S (Soil/Sed.) **GW** (Ground Water) **SW** (Surface Water) **SS** (Storm/Sanitary Sewer) **P** (Paint) **A** (Air) **O** (Other)

Required Analyses

Paracel Order Number: 2317500

	Sample ID/Location Name	Matrix	Air Volume	# of Containers	Sample Taken Date	Time	ASTM D2974, Organic Matter, Method A	Resistivity	PH	Sulphate & Chloride							
11	BH23-3, SS10A, 22½-24½ ft	Soil		1	March 27, 2023	AM	X										
12	BH23-3, SS13	Soil		1	March 27, 2023	AM		X	X	X							
13	BH23-4, SS2, 2½-4½ ft	Soil		1	March 28, 2023	AM	X										
14	BH23-4, SS4, 7½-9½ ft	Soil		1	March 28, 2023	AM	X										
15	BH23-4, SS6, 12½-14½ ft	Soil		1	March 29, 2023	AM	X										
16	BH23-4, SS7, 15-17 ft	Soil		1	March 29, 2023	AM		X	X	X							
17	BH23-4, ST8, 17½-19½ ft	Soil		1	March 29, 2023	AM	X										
18	BH23-4, SS9A, 20-22 ft	Soil		1	March 29, 2023	AM	X										
19	BH23-8, SS7B, 15-17 ft	Soil		1	March 29, 2023	AM	X										

Comments: Temperature at 440 °C +/- 40°C for organic contents

Method of Delivery: Swift

Relinquished By (Print & Sign): Daniel Boateng [signature]	Received by Driver/Depot:	Received at Lab: Juneeam Bhmai	Verified By: Sandu Dempsins
	Date/Time:	Date/Time: APR 28, 2023 09.27	Date/Time: April 28 11:09
Date/Time: April 27, 2023	Temperature: °C	Temperature: 23.4 °C	pH Verified [ ] By:

Paracel_Chemical Testing & Organic Content.xlsx

APPENDIX D

D.1 2015 NATIONAL BUILDING CODE SEISMIC HAZARD CALCULATION

D.2 FIGURES D1 TO D4: SLOPE STABILITY ANALYSIS RESULTS

2015 National Building Code Seismic Hazard Calculation

INFORMATION: Eastern Canada English (613) 995-5548 français (613) 995-0600 Facsimile (613) 992-8836
Western Canada English (250) 363-6500 Facsimile (250) 363-6565

Site: 43.423N 80.275W

2023-05-25 20:00 UT

Probability of exceedance per annum	0.000404	0.001	0.0021	0.01
Probability of exceedance in 50 years	2 %	5 %	10 %	40 %
Sa (0.05)	0.123	0.067	0.039	0.010
Sa (0.1)	0.158	0.091	0.055	0.016
Sa (0.2)	0.141	0.084	0.052	0.017
Sa (0.3)	0.112	0.068	0.044	0.015
Sa (0.5)	0.084	0.053	0.035	0.012
Sa (1.0)	0.047	0.030	0.020	0.006
Sa (2.0)	0.024	0.015	0.009	0.002
Sa (5.0)	0.006	0.004	0.002	0.001
Sa (10.0)	0.002	0.001	0.001	0.000
PGA (g)	0.087	0.050	0.030	0.009
PGV (m/s)	0.067	0.040	0.025	0.007

Notes: Spectral (Sa(T), where T is the period in seconds) and peak ground acceleration (PGA) values are given in units of g (9.81 m/s^2). Peak ground velocity is given in m/s. Values are for "firm ground" (NBCC2015 Site Class C, average shear wave velocity 450 m/s). NBCC2015 and CSAS6-14 values are highlighted in yellow. Three additional periods are provided - their use is discussed in the NBCC2015 Commentary. Only 2 significant figures are to be used. **These values have been interpolated from a 10-km-spaced grid of points. Depending on the gradient of the nearby points, values at this location calculated directly from the hazard program may vary. More than 95 percent of interpolated values are within 2 percent of the directly calculated values.**

References

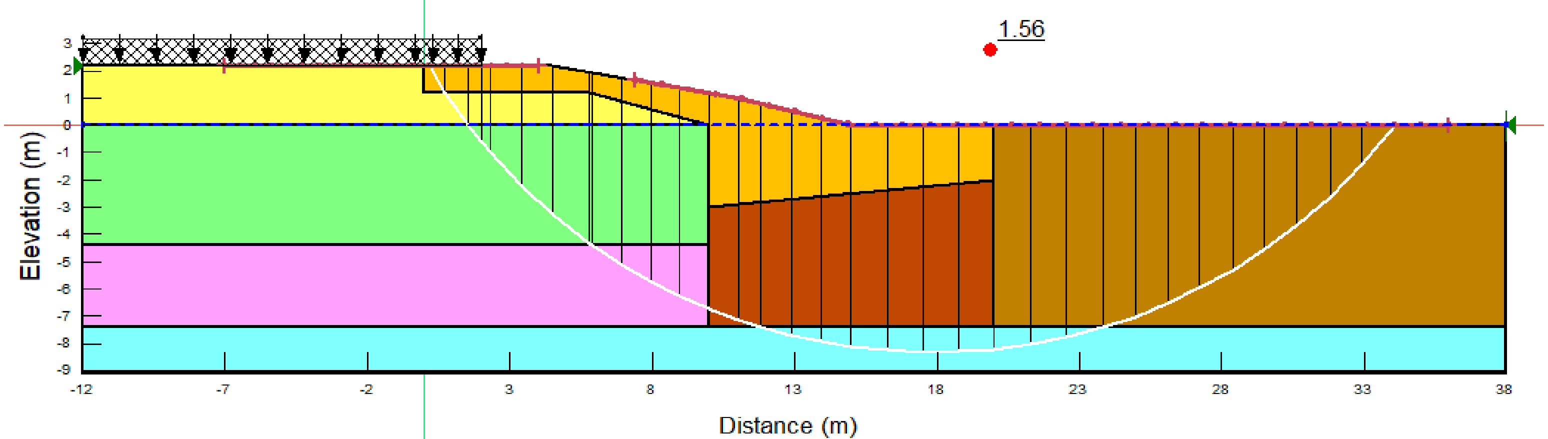
National Building Code of Canada 2015 NRCC no. 56190; Appendix C: Table C-3, Seismic Design Data for Selected Locations in Canada

Structural Commentaries (User's Guide - NBC 2015: Part 4 of Division B)
Commentary J: Design for Seismic Effects

Geological Survey of Canada Open File 7893 Fifth Generation Seismic Hazard Model for Canada: Grid values of mean hazard to be used with the 2015 National Building Code of Canada

See the websites www.EarthquakesCanada.ca and www.nationalcodes.ca for more information

Color	Name	Unit Weight (kN/m³)	Cohesion (kPa)	Effective Friction Angle (°)
	Embankment fill (compact sand and gravel)	22		31
	Fill: silt to sandy silt (very loose to loose)	18		25
	Fill: silty sand to sand (very loose to compact)	19		29
	New fill (Granular A or B Type II)	22		35
	Peat	10.5	8	
	Peat (consolidated)	11.7	30	
	Sity sand to sand (very loose to compact)	19		30

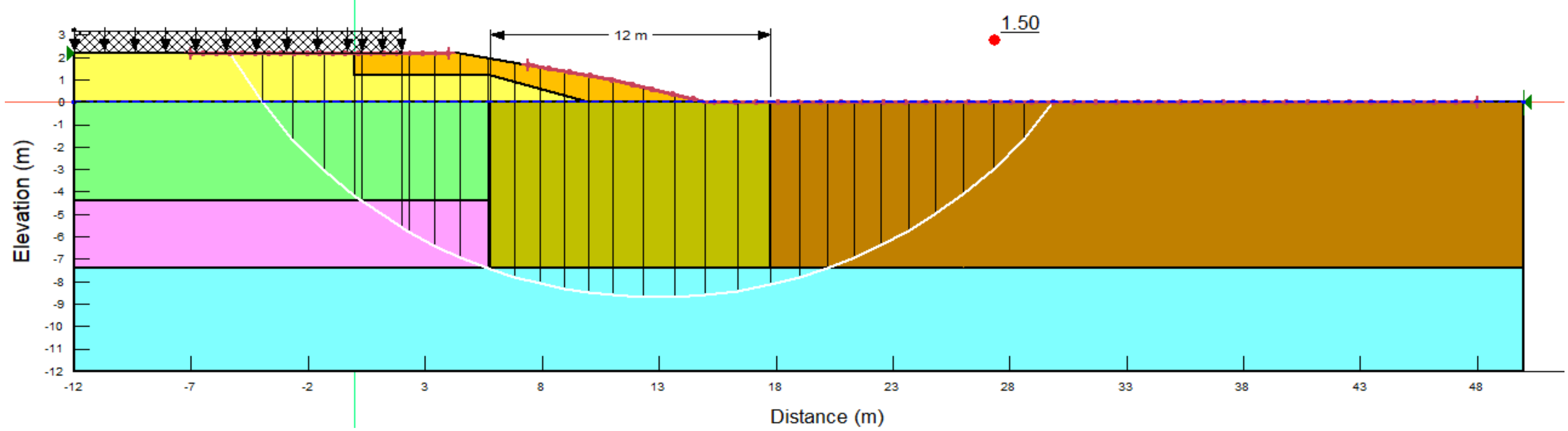


Stantec

Static Short-term Slope Stability Analysis
Preload and Surcharge
HWY 401 Improvements, Stage 4A, Muskeg Subgrade

Figure D1
Project No. 165000897
MTO

Color	Name	Unit Weight (kN/m³)	Cohesion (kPa)	Effective Friction Angle (°)
Yellow	Embankment fill (compact sand and gravel)	22		31
Pink	Fill: silt to sandy silt (very loose to loose)	18		25
Green	Fill: silty sand to sand (very loose to compact)	19		29
Orange	New fill (Granular A or B Type II)	22		35
Brown	Peat	10.5	8	
Olive	Peat (stabilized by deep soil mixing)	12.5	150	
Cyan	Sity sand to sand (very loose to compact)	19		30



Stantec

Static Short-term Slope Stability Analysis

Deep Soil Mixing

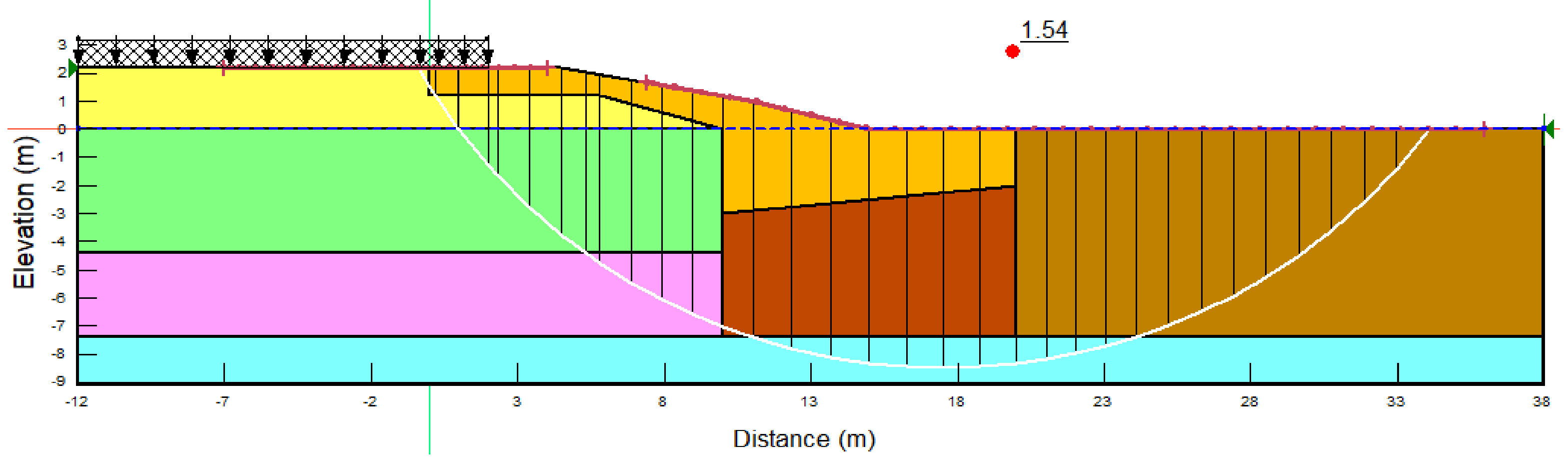
HWY 401 Improvements, Stage 4A, Muskeg Subgrade

Figure D2

Project No. 165000897

MTO

Color	Name	Unit Weight (kN/m³)	Effective Friction Angle (°)
Yellow	Embankment fill (compact sand and gravel)	22	31
Pink	Fill: silt to sandy silt (very loose to loose)	18	25
Green	Fill: silty sand to sand (very loose to compact)	19	29
Orange	New fill (Granular A or B Type II)	22	35
Brown	Peat	10.5	36
Dark red	Peat (consolidated)	11.7	36
Cyan	Sity sand to sand (very loose to compact)	19	30



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Static Long-term Slope Stability Analysis

Preload and Surcharge

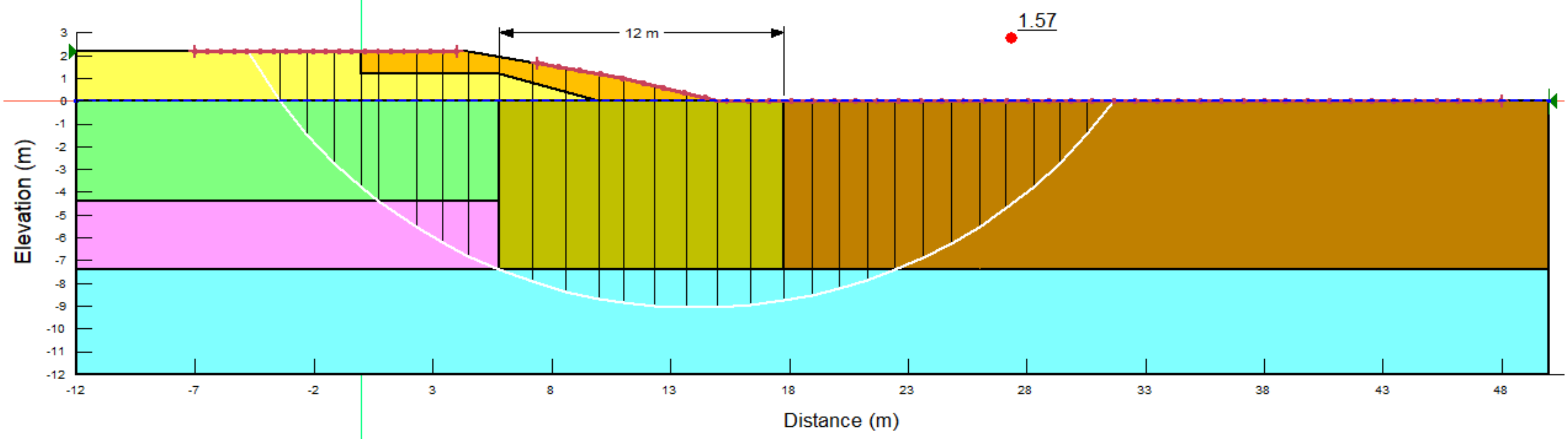
HWY 401 Improvements, Stage 4A, Muskeg Subgrade

Figure D3

Project No. 165000897

MTO

Color	Name	Unit Weight (kN/m³)	Effective Friction Angle (°)
	Embankment fill (compact sand and gravel)	22	31
	Fill: silt to sandy silt (very loose to loose)	18	25
	Fill: silty sand to sand (very loose to compact)	19	29
	New fill (Granular A or B Type II)	22	35
	Peat	10.5	36
	Peat (stabilized by deep soil mixing)	12.5	36
	Sity sand to sand (very loose to compact)	19	30



Stantec

Static Long-term Slope Stability Analysis

Deep Soil Mixing

HWY 401 Improvements, Stage 4A, Muskeg Subgrade

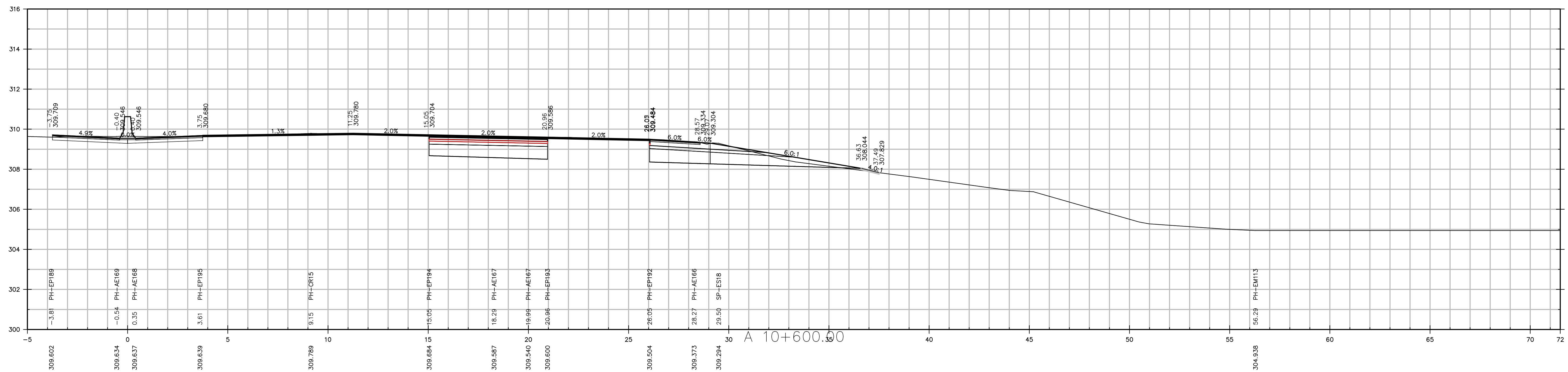
Figure D4

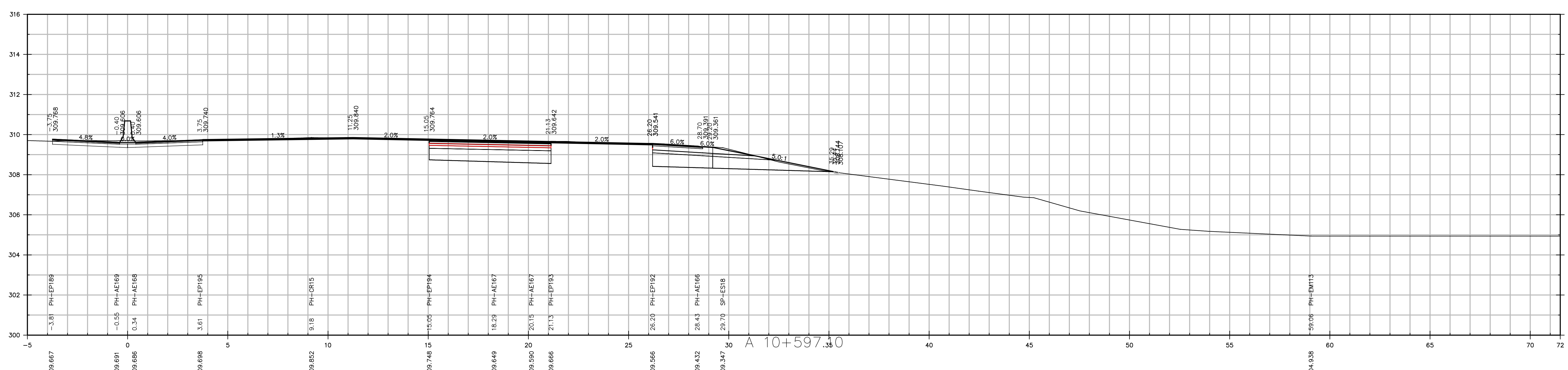
Project No. 165000897

MTO

APPENDIX E

E.1 SELECTED HIGHWAY EMBANKMENT CROSS SECTIONS





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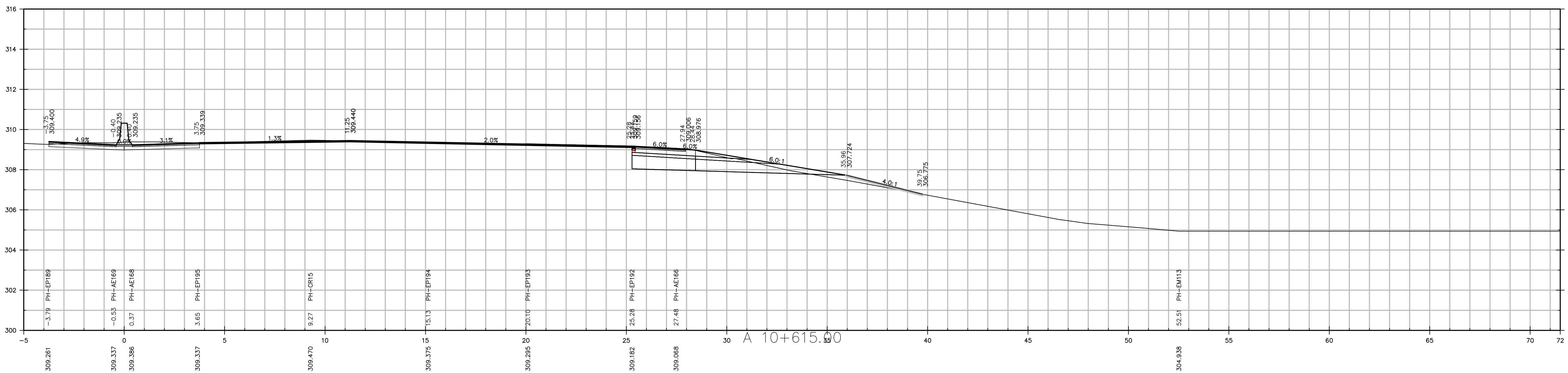
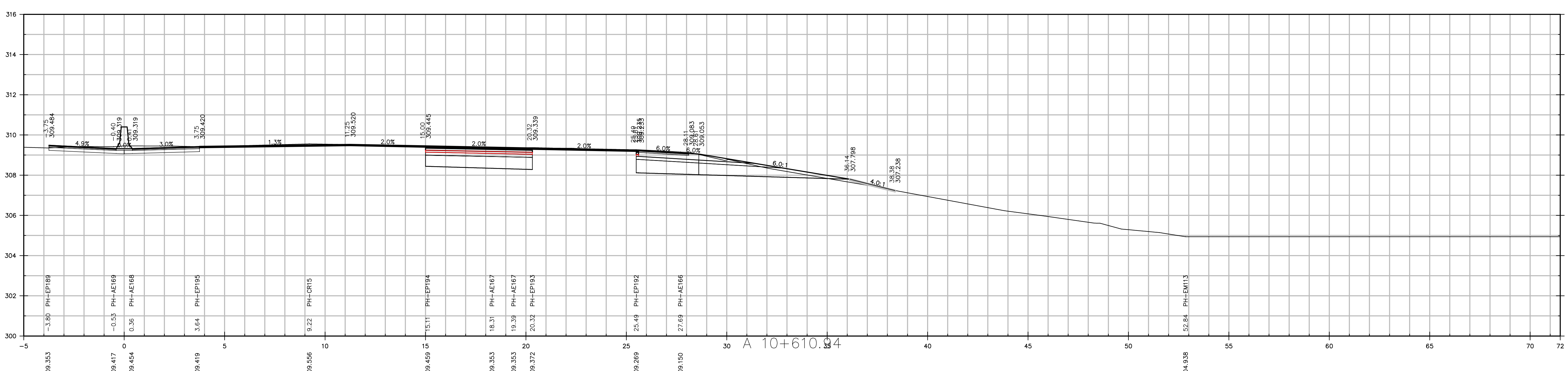
STA A 10+610.94 TO STA A 10+615.00





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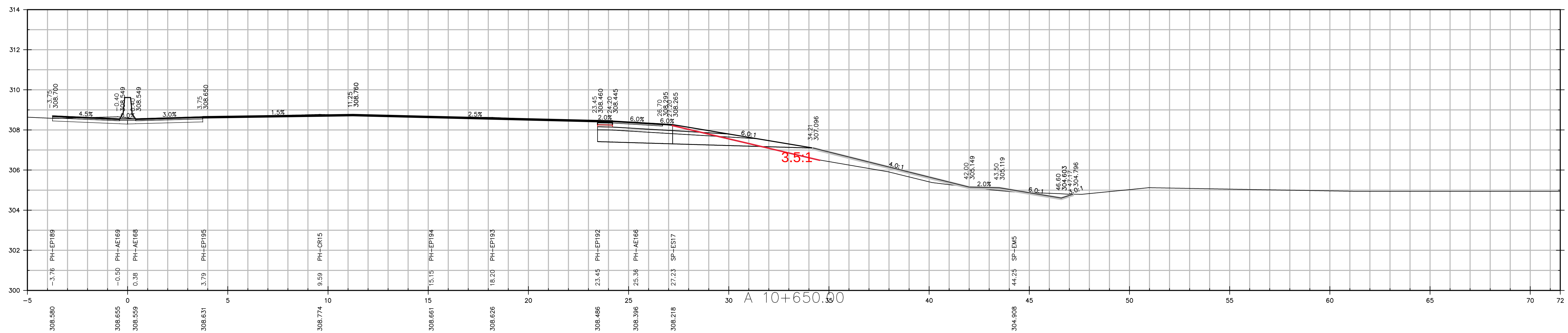

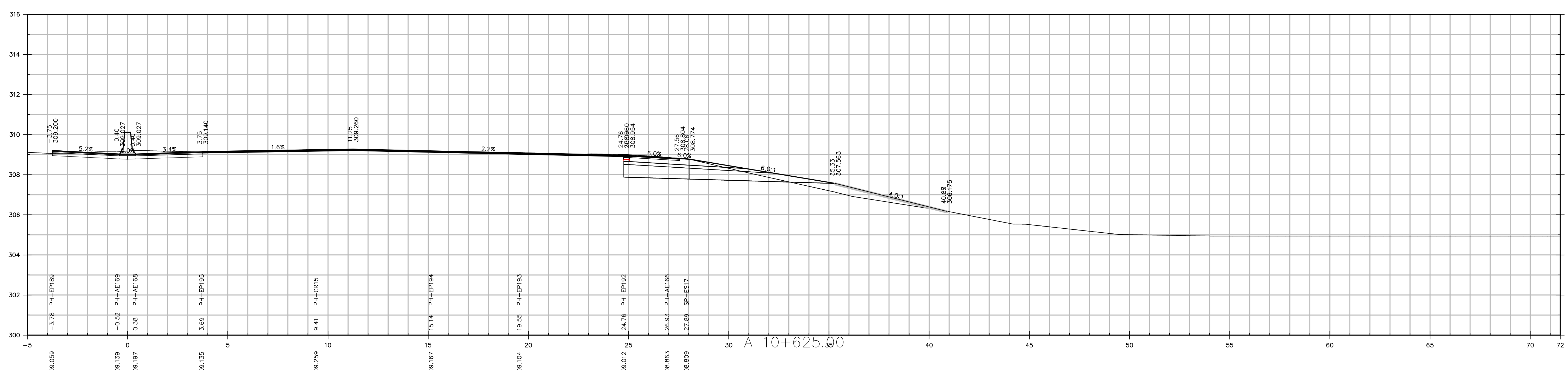

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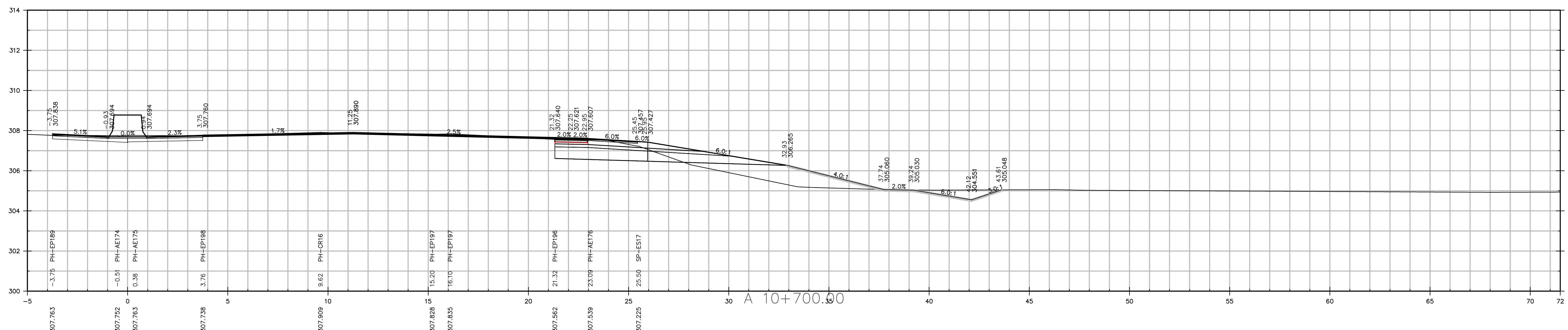

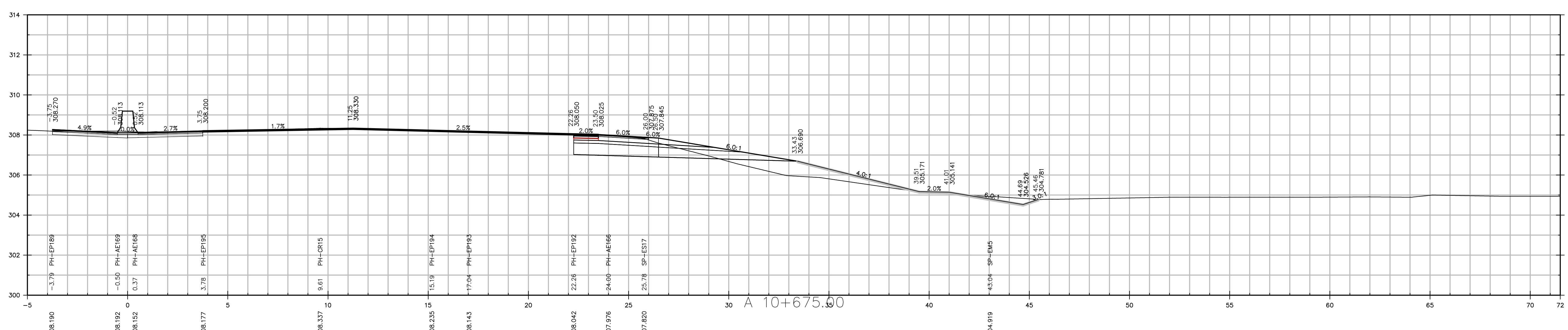

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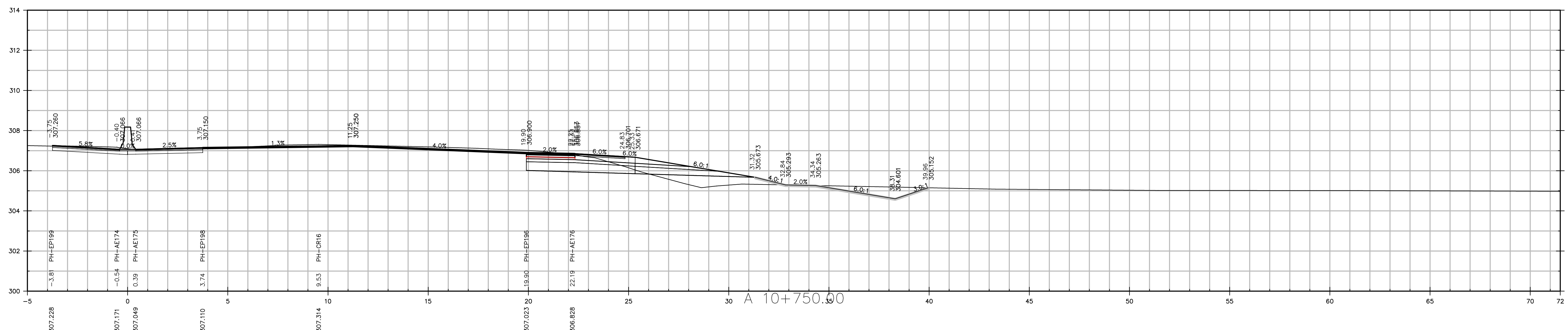

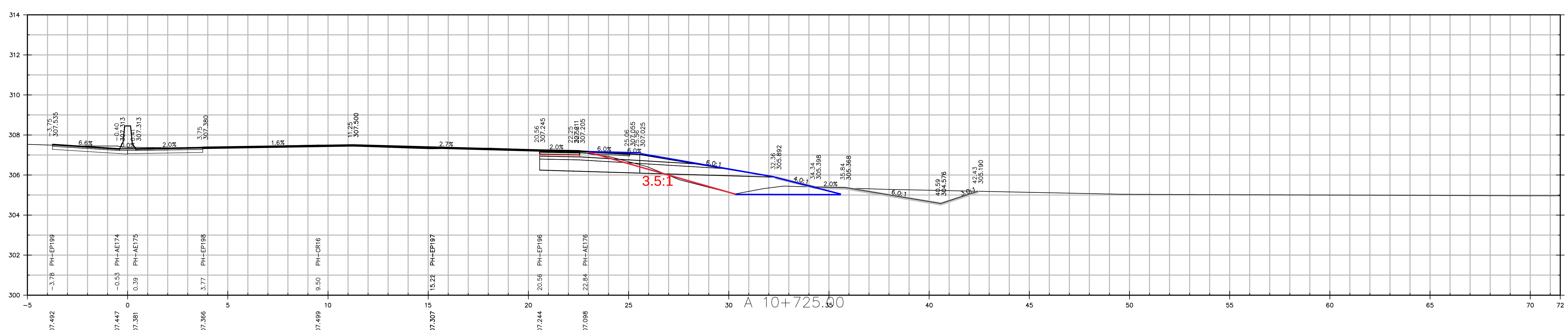

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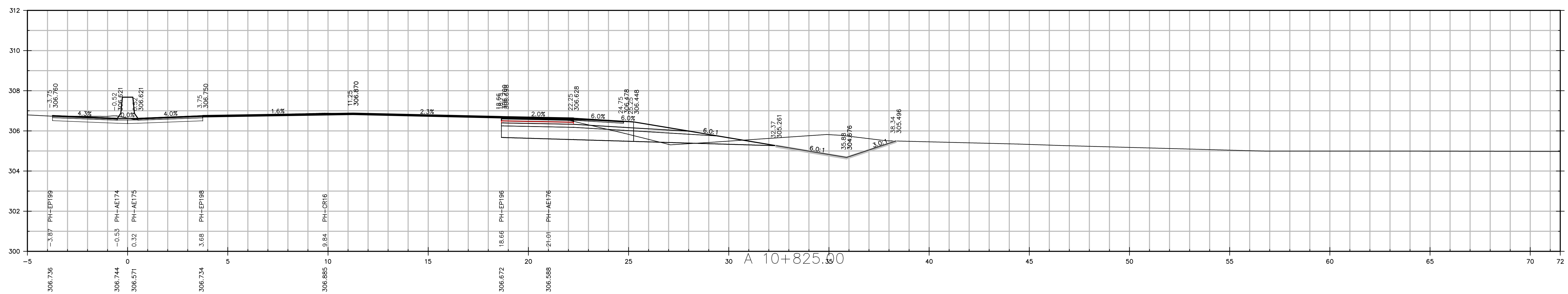
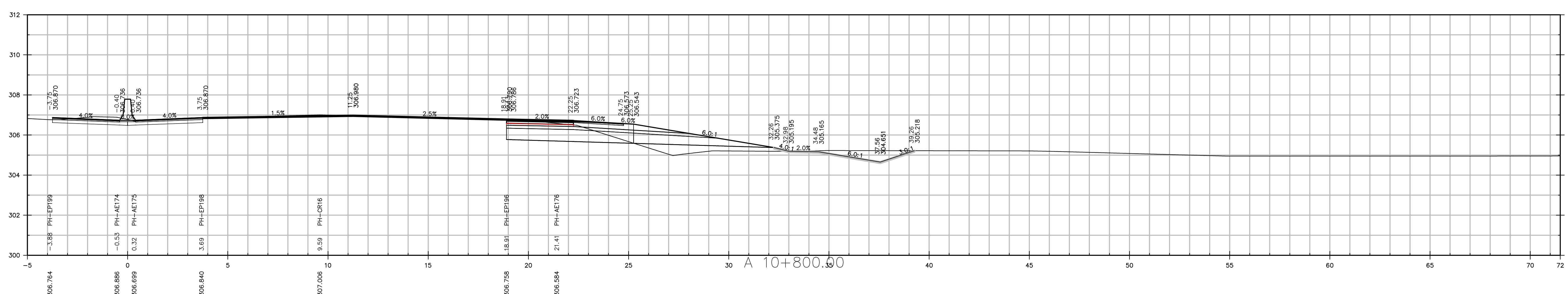
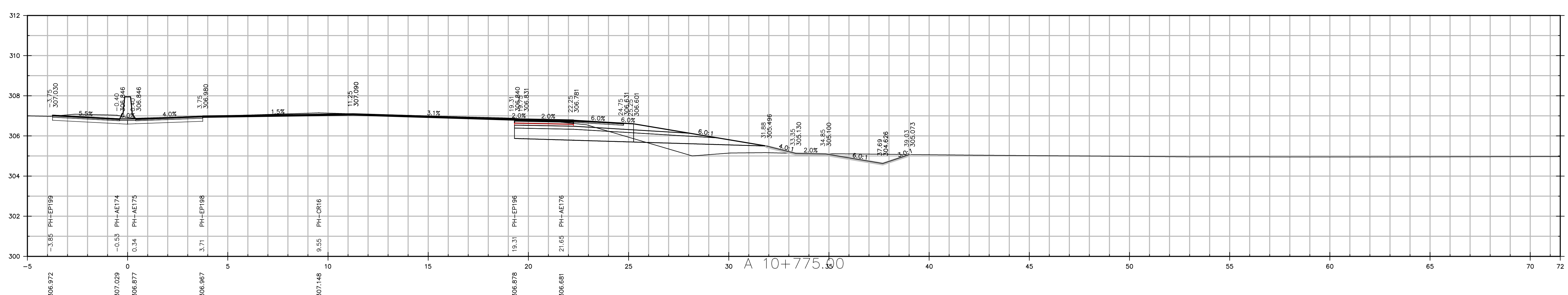
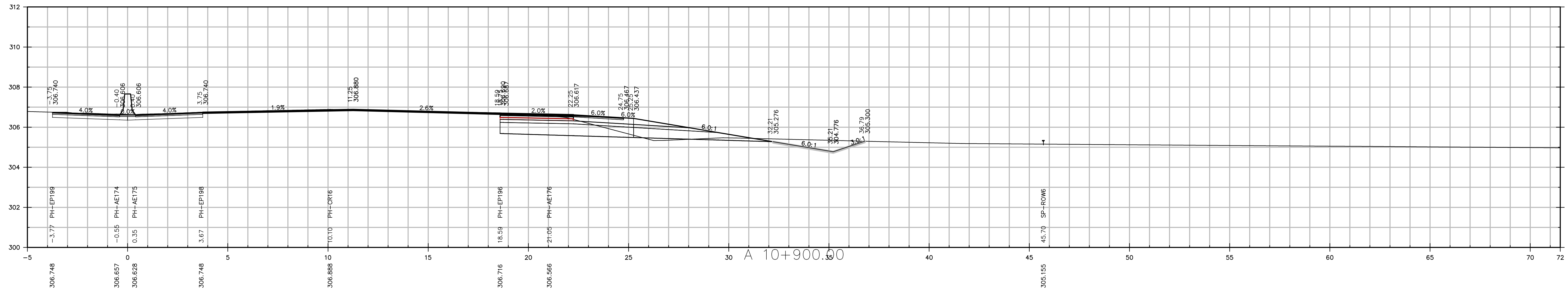
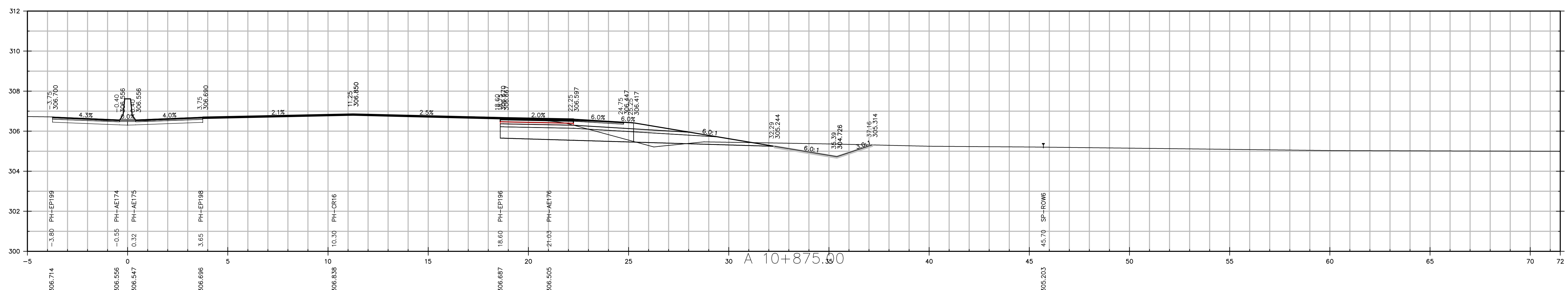


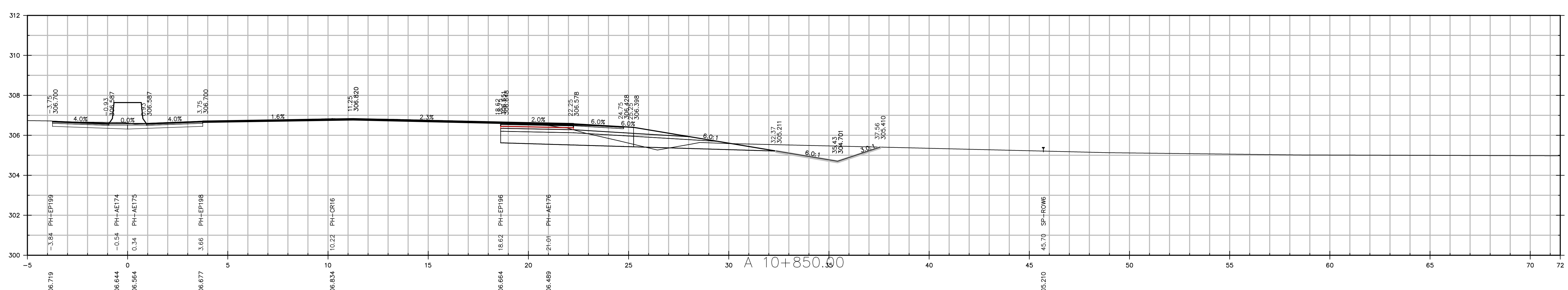




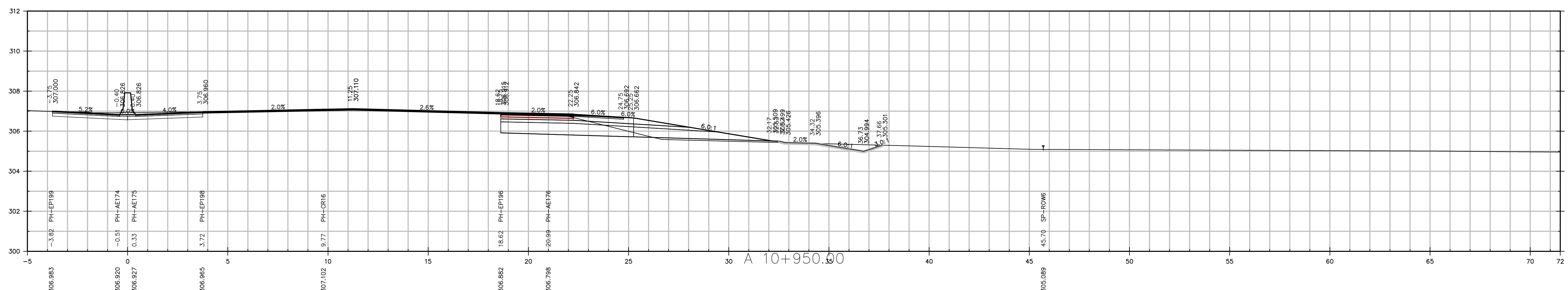
STA A 10+850.00 TO STA A 10+900.00







STA A 10+925.00 TO STA A 10+950.00



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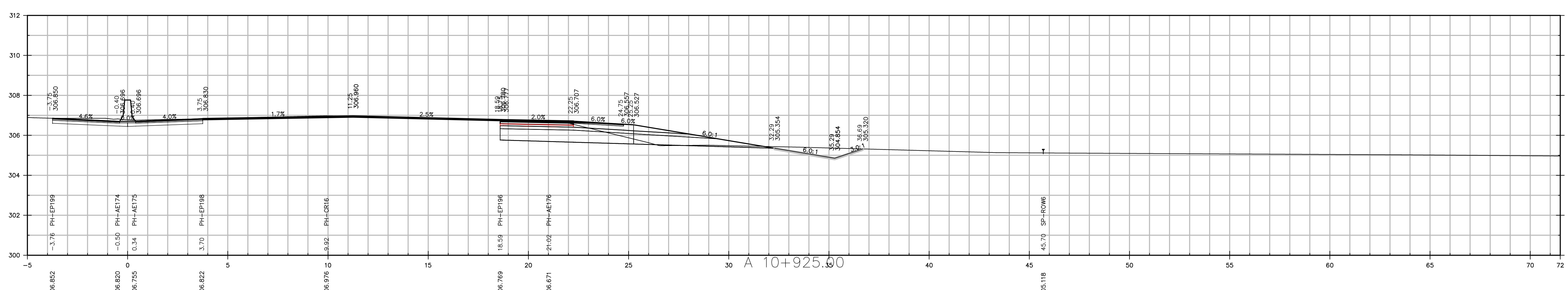

A 10+925.00

APPENDIX F

F.1 TABLE F-1 COMPARISON OF SOIL IMPROVEMENT OPTIONS FOR PEAT DEPOSIT

Table F1: Comparison of Soil Improvement Options for Peat Deposit

Option		Advantages	Disadvantages	Feasibility
A. Mass Peat Replacement	Excavation and replacement – Complete peat removal from beneath the existing embankment slope and the proposed embankment area. - Replace with rockfill placed in the wet - Replace with compacted soil within watertight shoring system	Large pool of qualified contractors	Treatment area of 300m by 12m for a rockfill core construction extending from future rounding Parallel sheet-piles, at existing shoulder rounding, and about 12 m beyond, with additional sheet piles at the end of excavation sections Whalers anticipated to for internal bracing Dewatering of excavation, sump and pump methods are not appropriate	Feasible Similar to constructing a waterfront wharf
	Peat displacement (mud wave approach)	Relatively cheap	Requires removal of peat fill and fibrous peat crust Requires displacement trenches in the bog to receive the displaced peat Could impact shallow underground services	Not feasible
B. Soil (Peat) Improvement Methods	Pre-compression o Preloading and Surcharging o With staged construction	Placement of 2.5 m of fill for three months as surcharge could reduce consolidation settlement	About 5 m of fill required to raise the profile about 2 m. Requires staged construction, typically in 300 m to 500 mm lifts – therefore over 10 lifts anticipated. Slow - time required for peat consolidation between lifts and during surcharge Does not eliminate secondary long-term compression, anticipated mostly beneath future shoulder and embankment slope	Feasible If 2 weeks per 500 mm lifts, then assumed 20 weeks to construct, plus 20 weeks to compress under the surcharge
	Reinforcement o Synthetic georeinforcements o Geocell mattress o Timber grillage	Method could be used in conjunction with surcharging to reduce embankment movements	Does not address embankment settlement	Not Feasible

	Load modification o Lightweight fill (e.g., Light Weight Aggregate (LWA), Expanded Polystyrene (EPS), Lightweight Concrete (LWC) …) o Counter berm o Profile lowering	 Relatively rapid Relatively cheap Relatively cheap	 Lightweight fill such as polystyrene blocks are not practical due to buoyancy issues with the high groundwater level Not practical due to extent of the peat deposit Profile lowering not practical since it is a widening, set profile	Not Feasible Profile height is considered too low to allow for a lightweight fill approach
	Deep stabilization (deep soil mixing) o For the whole peat layer or to a targeted depth o Combination of mass and column stabilization	Reduces both consolidation and secondary compression settlement of peat Increase undrained strength of the peat Dry mixing methods provide very low spoil volumes.	Relatively expensive The wet method produces a significant volume of spoils	Feasible Full depth or combination of mass and column stabilization - Feasible Partial depth- Not feasible
C. Load Transfer to the Underlying Soils	Piles (concrete or steel piles) and concrete slab or georeinforcement	Address the settlement issue	Requires presence of a competent layer below peat deposit	Not feasible
	Wooden piles and geo reinforcement	Address the settlement issue	Requires presence of a competent layer below peat deposit	Not feasible
	Columns o Non-rigid (e.g., Stone columns, rammed aggregate piers) o rigid or semi-rigid inclusion (e.g., CMCs, Concrete or soil-cement mixture columns)	Non-rigid inclusions are cheaper than rigid-semi rigid inclusions	Requires a competent layer beneath the peat Construction of a work platform on the peat will trigger consolidations – work platform constructed in lifts – possibly over 4 m of granular materials to build platform No confinement from the surrounding peat while the columns are constructed, requiring plastic or steel liners prior to concrete setting in the case of rigid or semi-rigid inclusions Load transfer platforms would be constructed above the work platform level, already undergoing long term consolidation	Not feasible: Stone columns, rammed aggregate piers Feasible if combined with a surcharge program: rigid or semi-rigid inclusions – would require deep boreholes to find competent bottom The use of a CMC approach at this site would require - Surcharging the site - Excavating to below the load transfer pad level - Installing the CMCs - Constructing the load transfer platform, then the highway
Adopted and modified after Table 1 from "F. Juha, K. Leena, and P. Pyry (2018). Mass Stabilization as a Ground Improvement Method for Soft Peaty."				