THURBER ENGINEERING LTD.

FOUNDATION INVESTIGATION AND DESIGN REPORT
RETAINING WALL FOR SHIRLEY AVENUE WIDENING
REGIONAL MUNICIPALITY OF WATERLOO
G.W.P. 3104-15-00

GEOCRES NO.: 40P8-233

Report to

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PART 1: FACTUAL INFORMATION

1 INTRODUCTION

This report presents the factual findings obtained from a foundation investigation conducted at the site of a new retaining wall to be constructed on the south side of the proposed widening of Shirley Avenue in the Regional Municipality of Waterloo. Earth cuts are planned for the proposed roadway widening.

The purpose of the investigation was to explore the subsurface conditions at selected locations along the proposed wall alignment and, based on the data obtained, to provide a borehole locations and soil strata drawing, records of boreholes, stratigraphic profile, laboratory test results and a written description of the subsurface conditions. A model of the subsurface conditions was developed from the data obtained during the course of the present investigation.

Thurber was retained by MMM Group Limited (MMM) to carry out the foundation investigation at this site on behalf of the Ministry of Transportation Ontario (MTO) under Consultant Assignment No. 2012-E-0007.

2 SITE AND PROJECT DESCRIPTION

Shirley Avenue is located some 500 m to the east of the Highway 85 and Wellington Street interchange in The Regional Municipality of Waterloo. As part of the proposed Highway 7 New project and realignment/widening of Shirley Avenue, a 140 m long retaining wall will be constructed on the south side of the newly realigned section of Shirley Avenue. The new retaining wall will be located approximately 90 m east of Riverbend Drive.

The site is located within an area of industrial and commercial lands with a terrain gently sloping down towards the east. The Grand River is located approximately 380 m north of the site.

Based on a profile provided by MMM, the ground surface along the retaining wall alignment varies west to east from Elevations 323.2 to 320.8 m between approximate Stations 10+510 and 10+650 of the new Shirley Avenue. Randomly placed fill consisting of a heterogeneous mixture of soil and debris is located between approximate Stations 10+590 and 10+640. Cobbles and boulders were observed at some locations on the slopes. The random file stockpile is approximately 5.5 m high. At about Station 10+550, a small swampy area is present at the base of the fill stockpile. Immediately to the south of the random fill, the ground slopes up to a parking area adjacent to a commercial/industrial building.

Widening of Shirley Avenue involves an earth cut along the south side of the road alignment. The earth cut will be up to about 1.5 m deep within the western half of the wall alignment, and up to 6m deep at the random fill. The wall is to retain the proposed earth cut.

Photographs of the site showing the general nature of the surrounding lands are included in Appendix D.

Based on the Ontario Geological Survey Special Volume 2, The Physiography of Southern Ontario, Third Edition by Chapman and Putnam, the site lies within the physiographic region known as the Waterloo Hills, characterized by ridges of sandy till and kames or kame moraines, with outwash sands occupying the intervening hollows. Localized deposits of clayey silt/silty clay are also present. Undrained depressions or "kettles", formed amongst the hills during glaciation, are now generally occupied by organic deposits and seasonally intermittent water.

3 SITE INVESTIGATION AND FIELD TESTING

The site investigation and field testing for this project was carried out between January 8 and 12, 2015. A total of three boreholes (numbered 14-501, 14-502 and 14-503) were drilled and sampled along the proposed retaining wall alignment. Two additional boreholes were advanced on March 2 and 3, 2016. Details of borehole locations, depths and elevations are shown in Table 3.1.

Table 3.1 – Borehole Details

Approximate Location	Shirley Avenue Station	Borehole Number	Ground Elevation	Borehole Termination Depth (m)	Borehole Termination Elevation
West end of wall	10+500	14-501	322.6	9.8	312.8
Middle of wall	10+560	14-502	322.6	9.8	312.8
West end of fill pile	10+600	16-01	326.9	21.6	305.3
Middle of fill pile	10+615	14-503	326.4	12.8	313.6
East end of wall	10+635	16-02	326.3	21.8	304.5

The approximate locations of the boreholes drilled during the investigation are shown on the attached Borehole Locations and Soil Strata Drawing in Appendix C. The coordinates and elevations of the boreholes are given on the drawing and on the individual Record of Borehole

Sheets in Appendix A. The approximate locations of two pavement boreholes in the vicinity of the retaining wall are also shown on the plan.

The borehole locations were established in the field by Thurber relative to existing site features. Utility clearance were obtained at all borehole locations prior to drilling.

A truck mounted CME-55 and a track mounted D-120 drill rigs were used in conjunction with hollow-stem augers to advance the boreholes. Soil samples were obtained at selected intervals using a split spoon sampler in conjunction with the Standard Penetration Test (SPT).

The drilling and sampling operations were supervised on a full time basis by a member of Thurber's technical staff. The supervisor logged the boreholes and processed the recovered soil samples for transport to Thurber's laboratory for further examination and testing.

Groundwater conditions were observed in the open boreholes during and upon completion of the drilling operations. Standpipe piezometers consisting of a 19 mm diameter Schedule 40 PVC pipe with 1.5 to 3.0 m long slotted screens were installed within a column of filter sand in two boreholes to permit longer term groundwater level monitoring. The completion details of the piezometers and boreholes are summarized in Table 3.2.

Table 3.2 – Piezometer and Borehole Completion Details

Approximate location	Borehole Number	Piezometer Tip Depth / Elevation (m)	Completion Details
West end of wall	14-501	9.1/313.5	Backfilled with filter sand from 9.8 m to 7.1 m, bentonite holeplug from 7.1 m to 6.5 m, auger cuttings from 6.5 m to ground surface.
Middle of wall	14-502	None installed	Borehole backfilled with bentonite holeplug and auger cuttings from 9.8 m to ground surface.
West end of fill pile	16-01	None installed	Borehole backfilled with bentonite holeplug and auger cuttings from 21.6 m to ground surface.
East end	14-503	12.2/314.1	Backfilled with filter sand from 12.8 m to 7.6 m, bentonite holeplug and auger cuttings from 7.6 m to ground surface.
East end of wall	16-02	21.3/305.0	Backfilled with filter sand from 21.8 m to 16.1m, bentonite seal from 16.1 m to 15.5 m, bentonite holeplug and auger cuttings from 15.5m to 0.6 m, concrete from 0.6 m to ground surface.

4 LABORATORY TESTING

All recovered soil samples were subjected to visual identification and to natural moisture content determination. At least 25% of the recovered soil samples were subjected to grain size distribution analysis. Atterberg Limits tests were carried out on selected samples of cohesive soils to determine their plasticity characteristics. The results of the laboratory testing are summarized on the Record of Borehole sheets included in Appendix A and are presented on the figures included in Appendix B.

5 DESCRIPTION OF SUBSURFACE CONDITIONS

Reference is made to the Record of Borehole sheets in Appendix A. Details of the encountered soil stratigraphy are presented in these records and on the "Borehole Locations and Soil Strata" drawing in Appendix C. General description of the stratigraphy is given in the following paragraphs. The factual information established at the borehole locations governs any interpretation of the site conditions.

The stratigraphy near the alignment of the proposed retaining wall typically consists of topsoil overlying native loose to compact sand and silt which is underlain by very stiff to hard silty clay. Near the east end of the wall, a random fill stockpile up to 5.5 m in height was encountered below a surficial layer of asphalt. The fill consists of a random mixture of silty sand, gravel and clay pockets with debris, organics, decayed wood, metal and asphalt fragments. There was also occasional evidence of cobbles, boulders and other obstructions.

5.1 Topsoil

Topsoil of 50 mm in thickness was contacted surficially in Boreholes 14-501 and 14-502. Up to 300 mm of topsoil was encountered in Borehole 16-02.

The topsoil thickness may vary between and beyond the borehole location and the data is not intended for the purpose of estimating quantities.

5.2 Pavement Structure

Pavement structure consisting of asphalt overlying granular fill materials was encountered in Borehole 14-503, drilled near the east end of the proposed retaining wall in a parking lot. The asphalt was 200 mm in thickness.

5.3 Fill

Brown to grey gravelly sand, sand to silty sand fill containing some gravel, some silt to silty, some clay with clay pockets was contacted below the asphalt in Borehole 14-503, below the topsoil in Borehole 16-02, and at ground surface in Borehole 16-01. Odour was noted in the fill samples. The fill also contained debris, organics, decayed plywood, metal and asphalt fragments. Cobbles and boulders were also noted at some locations on the slope face.

Thurber conducted a pavement investigation at this site which included two pavement boreholes that were attempted from the top of the random fill, and located at offset 10 and 12 m RT of CL at Sta. 10+600. The first hole was terminated at about 3 m depth when an obstruction was encountered and concrete fragments were observed in the auger cuttings. A second attempt was made at 2 m to the north and was also terminated at about 3 m depth when the augers became wrapped in a ¾" diameter wire rope.

Based on the foundation and pavement field investigations, it is apparent that the random fill comprises a sandy matrix with random inclusions of debris and rubble as outlined above.

The thickness of the fill in Borehole 14-503, 16-01 and 16-02 was 5.4 m, 7.6 m and 7.5 m, respectively. The depth to the base of the fill ranged between 5.6 m and 7.8 m (Elevations 318.5 to 320.8 m).

The SPT 'N' values measured in the fill typically ranged from 0 to 17 blows per 0.3 m of penetration indicating a very loose to compact condition. An SPT 'N' value of 30 blows per 0.3m of penetration was encountered in Borehole 14-503 immediately below the asphalt indicating a compact to dense state. An SPT 'N' value of 41 blows per 0.3 m of penetration was encountered in Borehole 16-02 at 3 m depth indicating a dense state with the presence of probable cobbles and boulders. The moisture content of the sand fill ranged from 4% to 13%.

Five samples of the fill were subjected to laboratory gradation analysis. Grain size distribution curves for the tested samples are presented on the Record of Borehole sheets included in Appendix A and on Figure B1 of Appendix B. The results of the laboratory test are summarized as follows:

Soil Particles	Percentage (%)
Gravel	4 to 22
Sand	44 to 56
Silt	23 to 30
Clay	5 to 15

5.4 Sand and Silt

An upper layer of native dark brown to brown sand and silt containing trace to some clay, occasional roots, rootlets and organics was contacted below the topsoil in Boreholes 14-501 and 14-502. The thickness of the sand and silt layer ranged from 4.5 to 2.3 m. The depth to the base of the sand and silt was 4.6 m and 2.4 m (Elevations 318.0 and 320.2 m) in Boreholes 14-501 and 14-502, respectively.

In Borehole 14-503, a 1.9-m thick lower layer of sand and silt was encountered below a layer of sand at 7.2 m depth. In this borehole, the sand and silt layer was mixed with organics and contained some clay, trace gravel and occasional roots and rootlets. A 300 mm thick layer of sand was encountered within this deposit near Elevation 317.5 m. Odour was identified in a sample of this soil. Readings taken by a Photo-Ionization Detector (P.I.D.) were less than 10 ppm. The depth to the base of the sand and silt was at 9.1 m (Elevation 317.2 m).

In Borehole 16-01, a 0.9 m thick layer of sand and silt was encountered between 16.8 m and 17.7 m depths (base Elevation 310.1 m). In Borehole 16-02, a 3.7 m thick sand and silt layer was encountered between 16.3 m and 20.0 m depths (base Elevation 306.3 m). These layers are in a compact state as indicated by an SPT 'N' values of 15 and 25 blows per 0.3m penetration, except at 18.3 m depth where an "N" value of greater than 100 blows for less than 0.3 m penetration indicated the probable presence of cobbles.

In Boreholes 14-501 and 14-502, the SPT 'N' values of the sand and silt ranged from 5 to 31 blows per 0.3 m of penetration, indicating a loose to dense state. An SPT 'N' value of 55 blows per 0.3 m of penetration was measured in Borehole 14-501 near Elevation 319.5m indicating a very dense condition. In Borehole 14-503, the sand and silt was in a very loose state as indicated by an SPT 'N' value of 2 blows per 0.3 m of penetration.

The moisture content of sand and silt samples ranged from 9% to 24%. A moisture content of 64% was measured in Borehole 14-502 near 0.6 m depth.

Samples of the sand and silt were subjected to laboratory gradation analysis. Grain size distribution curves for these tests are presented on the Record of Borehole sheets included in Appendix A and on Figure B2 of Appendix B. The results of the laboratory tests are summarized as follows:

Soil Particles	Percentage (%)
Gravel	0 to 7
Sand	34 to 54
Silt	34 to 59
Clay	3 to 14

5.5 Silty Clay

Below the sand and silt, native brown to grey silty clay containing trace sand and gravel was encountered in the five boreholes at various depths and elevations. In Borehole 14-

501, the silty clay was 2.6 m thick and contacted at 4.6 m depth. The base of this soil was at 7.2 m depth (Elevation 315.4 m). In Borehole 14-502, the silty clay was 6.6 m thick and contacted at 2.4 m depth. The base of this soil was at 9.0 m depth (Elevation 313.6 m). Borehole 14-503 encountered silty clay at 9.1 m depth and was terminated at 12.8 m depth (Elevation 313.6 m) in the silty clay.

In Boreholes 16-01 and 16-02, silty clay was encountered below the fill and a thin veneer of silty sand. This deposit extends to 16.3 m to 16.8 m depths (Elevations 310.0 to 310.1 m) in these boreholes.

The SPT ‘N’ values measured in the silty clay typically ranged from 15 to 47 blows per 0.3 m of penetration indicating a very stiff to hard consistency. SPT ‘N’ values of 13 and 14 blows per 0.3 m of penetration were measured at the top surface of this deposit in Borehole 14-503 and at a lower elevation in Borehole 16-01, indicating the presence of stiff zones.

The moisture content of the silty clay ranged from 16% to 23%.

Samples of the silty clay were subjected to gradation analysis and Atterberg Limits testing. Grain size distribution results are presented on the Record of Borehole sheets in Appendix A and on Figures B3 and B4 in Appendix B. Atterberg Limits test results are shown on the Records of Boreholes and also presented on Figures B6 and B7 of Appendix B. The results of the laboratory test are summarized as follows:

Soil Particles	Percentage (%)
Gravel	0
Sand	0 to 5
Silt	33 to 53
Clay	47 to 67

Soil Particles	Percentage (%)
Liquid Limit	31 to 43
Plasticity Index	15 to 25

The results indicate that the silty clay has a typically medium plasticity (CI) with some low plastic zones (CL).

5.6 Sand

Brown to grey upper sand containing some silt, trace gravel and trace clay was contacted below the silty clay at 7.2 m and 9.0 m in Boreholes 14-501 and 14-502, respectively. Boreholes 14-501 and 14-502 were terminated within the sand layer at 9.8 m depth (Elevation 312.8m). In Borehole 14-503, a 1.6 m thick sand layer was encountered below the fill at 5.6 m depth. The depth to the base of the sand layer in Borehole 14-503 was at 7.2 m (Elevation 319.2 m). In Borehole 16-01, a lower sand layer was encountered between 17.7 m and 20.4 m depths (base Elevation 306.5 m).

Measured SPT ‘N’ values in the sand were 41, 50 and 70 blows per 0.3 m of penetration in Boreholes 14-501 and 14-502, indicating a dense to very dense condition. An SPT ‘N’ value measured in Borehole 14-503 was 2 blows per 0.3 m of penetration indicating a very loose state. In Borehole 16-01, an SPT “N” value of 17 blows per 0.3 m penetration indicates a compact state, whereas a value of 100 blows was possibly due to a full split spoon sampler.

The moisture content of the sand ranged from 13% to 23%.

Two samples of the sand were subjected to laboratory gradation analysis. The grain size distribution curves are presented on the Record of Borehole sheets included in Appendix A and on Figure B5 of Appendix B. The results of the laboratory test are summarized as follows:

<table>
<tr><th>Soil Particles</th><th colspan="2">Percentage (%)</th></tr>
<tr><td>Gravel</td><td colspan="2">0</td></tr>
<tr><td>Sand</td><td colspan="2">79 to 91</td></tr>
<tr><td>Silt</td><td>17</td><td rowspan="2">9</td></tr>
<tr><td>Clay</td><td>4</td></tr>
</table>

5.7 Groundwater Level

Water levels were observed in the open boreholes upon completion of drilling operations. Three standpipe piezometers were installed to monitor water levels after completion of drilling. The water levels measured in the piezometers are summarized in Table 5.1.

Table 5.1 – Water Level Measurements

<table>
<tr><th rowspan="2">Borehole Number</th><th rowspan="2">Date</th><th colspan="2">Water Levels</th><th rowspan="2">Comment</th></tr>
<tr><th>Depth (m)</th><th>Elevation (m)</th></tr>
<tr><td rowspan="2">14-501</td><td>January 21, 2015</td><td>4.9</td><td>317.7</td><td rowspan="2">Piezometer</td></tr>
<tr><td>March 13, 2015</td><td>4.7</td><td>317.9</td></tr>
<tr><td>14-503</td><td>January 21, 2015</td><td>4.5</td><td>321.8</td><td>Piezometer</td></tr>
<tr><td>16-02</td><td>March 9, 2016</td><td>8.5</td><td>317.8</td><td>Piezometer</td></tr>
</table>

Piezometric readings indicated that the water level varies between Elevations 317.7 and 317.8 m within the lower sands and silts, and is at Elevation 321.8 m within the silty clay.

The groundwater readings at this site are short term observations. Seasonal fluctuations of the groundwater level are to be expected. In particular, the groundwater level may be at higher elevations after the spring snowmelt or after periods of heavy rainfall.

6 MISCELLANEOUS

The northing and easting co-ordinates and ground surface elevations of the completed boreholes were provided by MMM.

The drilling and sampling equipment were supplied and operated by ALTECH Drilling and Investigative Services of Elmira, Ontario and DBW Drilling of Ajax, Ontario

The field work was supervised on a full time basis by Mr. Abdul Nasri, Mr. Sean Petrus and Ms. Eckie Siu of Thurber.

Geotechnical laboratory testing was carried out at Thurber's MTO approved high complexity Toronto area laboratory.

Planning and co-ordination of the field program was conducted by Mr. Matthew Whalen, E.I.T. and Mr. Stephane Loranger, C.E.T.

Compilation of data and preparation of the report was carried out by Ms. R. Palomeque Reyna, P.Eng.

The report was reviewed by Dr. Sydney Pang, P.Eng. and Dr. P.K. Chatterji, P.Eng., a Designated Principal Contact for MTO Foundations Projects.

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PART 2: ENGINEERING DISCUSSION AND RECOMMENDATIONS

7 GENERAL

This report provides interpretation of the geotechnical data in the factual report and presents foundation design recommendations to assist the design team in selecting and designing a suitable foundation system for a new retaining wall to be located on the south side of the proposed Shirley Avenue widening in the Regional Municipality of Waterloo.

In order to realign and widen Shirley Avenue, an earth cut is proposed along the south side of the new alignment. The maximum depth of the cut is up to 6 m near Station 10+625 (near the easterly limit). Based on the profiles and sections provided by MMM, the retaining wall varies in retained height from approximately 1 to 6 m between Stations 10+510 and 10+650 (west to east). The length of the wall is approximately 140 m.

The discussion and recommendations presented in this report are based on design information provided by MMM to date and the factual data obtained during the course of this investigation. Selected field information from our pavement investigation has also been used in our assessment.

8 RETAINING WALL FOUNDATIONS

Between approximate Stations 10+510 (westerly limit) and 10+590, Boreholes 14-501 and 14-502 indicate that the stratigraphy at the site generally consists of topsoil overlying native typically loose to compact sand and silt overlying very stiff to hard silty clay. Dense to very dense sand was encountered below the silty clay. Between Stations 10+590 and 10+640, Boreholes 16-01, 16-02 and 14-503 encountered a 5.4 to 7.6 m thick stockpile of loose to compact gravelly sand to sand fill which contains debris and miscellaneous inclusions of wood, metal and asphalt fragments. The fill overlies layers of native very loose sands and silts, which are underlain by stiff to very stiff silty clay. Piezometric readings indicated that the water level was at Elevation 317.7 m within the lower sands and silts, and at Elevation 321.8 m within the silty clay.

8.1 Foundation Alternatives

Selection of the type of wall should take into consideration the height and configuration of the retained soil, the subsurface conditions along the wall alignment, and construction constraints. Consideration was given to the following retaining wall types:

- Concrete retaining wall founded on augered caissons
- Concrete retaining wall founded on driven H-piles
- Conventional concrete cantilever wall with granular backfill on spread footings
- Soldier pile and concrete panel wall
- Retained Soil System (RSS) wall
- Concrete toe wall

It is understood that consideration is being given to a cast-in-place concrete wall of the cantilevered type or supported on driven piles or caissons. Augered caissons and driven H-piles with sufficient embedment depth are feasible to provide lateral and vertical resistance for the wall. A concrete cantilever wall on footings requires excavation upslope for backfill placement and drainage installation. If space constraint is not an issue, this is a feasible foundation option for the westerly section (about 80 m in length) of the wall. In the vicinity of the existing fill stockpile, the footing option is not feasible because the underlying soils to about 4 m depth are very loose and below the local groundwater level (see Section 8.4 below for details).

A soldier pile and concrete panel wall is a technically feasible option at this site. This type of wall does not require excavation behind the wall and also serves the dual purpose of temporary shoring and a permanent wall. This option is, however, not being considered and foundation recommendations are therefore not developed.

An RSS wall requires significant excavation upslope for reinforcing strip installation and backfill placement. Temporary shoring may be required to facilitate construction of this type of wall. This option is not being considered and foundation recommendations are not developed.

The feasibility of a concrete toe wall depends on the retained height, configuration/geometry, and the wall embedment depth. For retained heights that are not greater than the order of 1.8 m, this type of wall may be considered.

The latest available GA drawing indicates that the fill stockpile section between approximate Stations 10+596 and 10+643 will be retained by a contiguous caisson wall comprised of alternate load carrying caissons and filler caissons. The remainder of the wall consists of a driven pile and precast concrete panel design.

Foundation recommendations for the types of retaining wall currently being considered are presented below.

8.2 Augered Caissons

8.2.1 Axial Resistance

Augered caissons embedded within the sand and silt and/or silty clay are feasible to support the retaining wall. Table 8.1 presents possible founding depths and elevations for the caissons as well as geotechnical resistances recommended for typical caisson diameters of 0.9, 1.05 and 1.2 m.

Table 8.1 – Founding Levels and Geotechnical Resistances for Augered Caissons to support the Retaining Wall

Caisson Length below final road grade* (m)	Approx. Founding Elevation (m)	Axial Geotechnical Resistance					
		Factored ULSf (kN)	SLS (25 mm settle-ment) (kN)	Factored ULSf (kN)	SLS (25 mm settle-ment) (kN)	Factored ULSf (kN)	SLS (25 mm settle-ment) (kN)
		0.9 m Diameter		1.05 m Diameter		1.2-m Diameter	
Stations 10+510 (west limit of wall) to 10+590 (west limit of random fill)							
5	317 to 316	400	320	550	440	700	560
10	313 to 311	900	720	1,200	960	1,500	1,200
Stations 10+590 to 10+650 (East Limit)							
10	311	780	620	1,050	850	1,300	1,050
12	309	950	750	1,250	1,000	1,650	1,300

*

* Approximate Elevations 321 to 322 m

Based on the GA drawing for the proposed wall, it is understood that the 1.05 m diameter load carrying caissons are to be founded at Elevation 309.0 m within the compact sands and silts, whereas the 1.2 m diameter filler caissons are to be founded at Elevation 319.0m.

8.2.2 Lateral Resistance

Lateral loadings can be geotechnically resisted by the caissons through passive pressure developed along the embedded portion of the shaft.

For lateral resistance design, soil-caisson interaction analyses may be carried out using the coefficient of horizontal subgrade reaction values provided in Table 8.2 below.

Table 8.2 – Recommended Geotechnical Parameters for Lateral Resistance Design

Approximate Elevation (m)	**Undrained Shear Strength C_u (kPa)**	**n_h (kN/m^3)**	**K_p**	**Unit Weight γ (kN/m^3)**	**Soil Conditions**
Stations 10+510 (West Limit) to 10+590					
G.S. to 319	-	3,000	3.0	20	Sand and Silt compact
319 to 315	200	-	-	20	Silty Clay hard
315 to 311	-	8,000	3.9	10*	Sand dense to very dense
Stations 10+590 to 10+650 (East Limit)					
Final grade to 318	-	1,000	2.8	19	Sand and Silt Very loose
318 to 310	125	-	-	20	Silty Clay very stiff
310 to 306	-	2,000	3.0	10*	Sand compact

* Submerged unit weight below the water table

The lateral resistance of a caisson may be calculated using values for the coefficient of horizontal subgrade reaction (k_s) and the lateral pressures obtained from the analysis should not exceed the ultimate values given in the following relationships.

Sands and Silts

$k_s = n_h \cdot z / D$ (kN/m^3)

$p_{ult} = 3 \cdot \gamma \cdot z \cdot K_p$ (kPa)

where p_{ult} = ultimate lateral resistance mobilized by a caisson, kPa
z = depth of embedment of caisson, m
D = caisson diameter, m
n_h = coefficient related to soil density, kN/m^3
γ = unit weight of soil, kN/m^3
(submerged indicated where appropriate)
K_p = passive earth pressure coefficient

Silty Clay

$k_s = 67\, C_u / D$ (kN/m^3)

$p_{ult} = 9\, C_u$ (kPa)

where C_u = undrained shear strength of cohesive soils, kPa

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The spring constant, K, for analysis may be obtained by the expression, $K = k_s \times d_z \times D$ (kN/m), where k_s is the coefficient of horizontal subgrade reaction (kN/m^3), D is the caisson diameter (m), d_z is the length (m) of the caisson segment or element used in the analysis. The ultimate lateral resistance on any one segment of caisson, P_{ult}, may be obtained from the expression, $P_{ult} = p_{ult} \times d_z \times D$. This represents the ultimate load at the contact between the soil and the caisson above which additional load cannot be supported at greater displacements.

For lateral soil-caisson group interaction analysis, the values for k_s should be reduced based on caisson spacing.

Where a caisson group is oriented ***perpendicular*** to the direction of loading, group action may be considered by reducing values of k_s using a reduction factor R as follows:

Caisson Spacing Perpendicular to Direction of Loading	Horizontal Subgrade Reaction Reduction Factor, R
4 D	1.00
1 D	0.50

where D is the diameter of the caisson, and spacing is measured centre to centre.

Where a caisson group is oriented parallel to the direction of loading, group action may be considered by reducing values of k_S using a reduction factor R as follows:

Caisson Spacing Parallel to Direction of Loading	Horizontal Subgrade Reaction Reduction Factor, R
8 D	1.00
6 D	0.70
4 D	0.40
3 D	0.25

Intermediate values may be obtained by interpolation.

8.2.3. Caisson Installation

Caisson installation must be carried out in accordance with OPSS 903.

There is potential of encountering oversized obstructions including debris, rubble, cobbles and boulders in the existing fill between approximate Stations 10+590 to 10+640.

Caisson excavation may encounter difficulties when advancing through the existing random fill stockpile. If any obstruction is encountered, the caisson installation equipment must be capable of handling, dislodging and removing such obstruction. In addition, water-bearing sands and silts under a hydrostatic head of at least 9 m will be encountered at the base of the load carrying caissons. An NSSP addressing these issues must be included in the contract documents to alert the bidders of these situations and present suggested methodologies to handle them (see Appendix F).

Soil sloughing and water seepage will occur in unsupported holes primarily from the existing fill and the native sands and silts. Construction of caissons will require use of a temporary steel liner to support the sidewalls of the excavation and to provide seepage cut-off. A balancing head of water inside the caisson hole may be required to minimize basal heave. Concrete should be placed with a minimum delay after each caisson is drilled and cleaned. Where water remains in the hole, the tremie technique should be used to place concrete inside the caisson hole. Where a balancing head of water is not used and the accumulated water can be pumped dry, conventional gravity methods may be used to place the concrete.

8.3 Steel H-piles

8.3.1 Axial Resistance

HP 310 x 110 piles may be used to support the retaining wall. The vertical, factored geotechnical resistances at Ultimate Limit States (ULS) and geotechnical resistances at Serviceability Limit States (SLS), and estimated pile tip elevations for 5 m and 10 m long pile are presented in Table 8.3.

Table 8.3 – Estimated Pile Tip Elevations and Axial Resistances of H-Piles

Approx. Pile Length below final grade (m)	Pile tip elevation (m)	HP 310 x 110	
		Factored ULS (kN)	SLS (kN)
Stations 10+510 (West Limit) to 10+590			
5	315 to 316	180	140
10	312	400	320
Stations 10+590 to 10+650 (East Limit)			
5	315	180	140
10	311	400	320

The SLS values correspond to a maximum pile settlement of 25 mm.

The piles should be driven to the specified design elevations. Pile driving control should be in accordance with the procedures described in Section 8.3.3 Pile Installation.

8.3.2 Lateral Resistance

For pile lateral resistance design, soil-pile interaction analyses may be carried out using the coefficient of horizontal subgrade reaction values provided in Table 8.2.

The methodology outlined in Section 8.2.2 above may be used to estimate the lateral geotechnical resistance of the pile by substituting the caisson diameter, D with the pile width, B.

8.3.3 Pile installation

All piles shall be installed in accordance with OPSS 903.

The appropriate wording for a pile driving note to be shown on the contract drawing is "Piles to be driven in accordance with Standard SS 103-11 using an ultimate geotechnical resistance equal to two (2) times the maximum factored design load at ULS per pile, but must be driven to or below Elevations 316 m or 315 m depending on the location as shown on the General Arrangement drawing of the Shirley Avenue retaining wall. The Hiley Formula does not need to be used until the pile tip is within 2 m above the design tip elevation.

The existing random fill near Stations 10+590 to 10+640 may contain obstructions which could interfere with or obstruct pile installation operations. The piles should initially be driven without tip reinforcement. Should there be obstructions that impede pile penetration and in order to minimize pile damage while driving through potential rubble, debris, boulders, cobbles and harder/dense zones to achieve the required tip elevations and soil resistance, then it is recommended that the remaining pile tips be reinforced with driving shoes such as the Titus Standard Point for H Piles. Consideration may also be given to pre-augering through the random fill prior to driving the piles.

8.4 Concrete Cantilever Wall

Design information provided by MMM indicates that the final road grade will slope in an easterly direction from the west wall limit to the west limit of the fill pile beyond which the road grade remains largely constant. The founding elevations of the concrete wall footings are expected to decrease in the same orientation. Approximate footing elevations at various stations along the wall alignment are summarized in Table 8.4 below.

Table 8.4 Preliminary Retaining Wall Design

Approximate Stations along wall alignment	Reference Borehole	Approximate Final Road Grade (m)	Approximate Footing Base Elevation (m)
10+510 to 10+590	14-501 14-502	323.0 sloping to 320.8	321.6 stepping down to 319.4
10+590 to 10+640	14-503	Not feasible due to poor soil conditions	

For the section adjacent to the existing random fill between approximate Stations 10+590 and 10+650, the upper 4 m of sands and silts are in a very loose state, which is unsuitable for supporting the footings.

8.4.1 Footings

The anticipated minimum depth of the footing founding level is 1.4 m below the final grade of the newly realigned Shirley Avenue. Based on Boreholes 14-501 and 14-502 and the founding levels in Table 8.4, it is recommended that conventional spread footings founded on native, undisturbed, compact to dense sand and silt, or very stiff to hard silty clay be designed for the following values:

- Factored Geotechnical Resistance at Ultimate Limit States (ULS) of 300 kPa
- Geotechnical Resistance at Serviceability Limit States (SLS) of 200 kPa.

The above design values are valid for a minimum footing width of 2 m. The design of stepped footings should be in accordance with the requirements in the Canadian Highway Bridge Design Code (CHBDC S6-06, revised 2010).

The above values are for vertical concentric loads only. Effects of load inclination and eccentricity need to be taken into account as per the CHBDC.

Resistance to lateral forces/sliding resistance between the concrete footings and the undisturbed native subgrade should be calculated in accordance with the CHBDC assuming an unfactored coefficient of friction, tan δ, of 0.4.

Once the desired footing subgrade level is reached, careful inspection should be carried out to delineate any remaining fill, organics, loose/softened or otherwise disturbed areas. Such areas should be sub-excavated down to the native soils and backfilled with mass concrete. It is recommended that a working mat of lean mix concrete be placed on the prepared and approved competent subgrade to provide protection from deterioration due to ponding water and construction traffic. Both the sand and silt, and the silty clay will be susceptible to disturbance and softening if exposed to ponded water or construction traffic.

8.4.2 Frost Penetration

For frost protection purposes, it is recommended that a minimum earth cover of 1.4 m, or its thermal equivalent, be provided to all footings.

8.5 Stability of Retaining Walls

Based on preliminary information provided by MMM, Thurber carried out limit equilibrium stability analyses for the proposed retaining wall for selected long and short term cases. A critical location along the wall where the retained height is up to 6 m has been selected. The stability analysis was carried out using the commercially available slope stability program GEO-SLOPE by employing the Morgenstern-Price method.

The computed Factor of Safety (F.S.) for the retaining wall configuration under drained and undrained conditions at this site is 1.5. Selected slope stability computation output is shown on Figures E1 and E2 of Appendix E.

As per typical MTO requirements, a F.S. of 1.3 is acceptable for short term or total stress (undrained) conditions. A F.S. of 1.5 is acceptable for long term (drained) conditions. The results indicate that these acceptance criteria are generally satisfied for the cases analysed.

8.6 Recommended Foundation

From a foundations technical, constructability and cost-effectiveness perspective, the recommended foundation option for the retaining wall at this site is augered caissons embedded within the native soils. Alternatively, driven steel H-piles is also a feasible option. As outlined previously, a contiguous caisson wall is proposed to retain the fill stockpile while a driven pile and concrete panel design is proposed for the remainder of the wall.

9 LATERAL EARTH PRESSURES

Backfill to the retaining walls should be in accordance with OPSS 902 and placed to the extents shown in OPSD 3101.150 where applicable. Any backfill to the walls should consist of Granular A or Granular B Type II material meeting the requirements of OPSS.PROV 1010.

If the support system allows yielding of the wall (unrestrained system), active horizontal earth pressure may be used in the geotechnical design of the structure. If the support system does not allow yielding (restrained system), at-rest horizontal earth pressures should be used.

Earth pressures acting on the structure may be assumed to be triangular and to be governed by the characteristics of the abutment backfill. For a fully drained condition, the pressures should be computed in accordance with the CHBDC but are generally given by the expression:

$$p_h = K (\gamma h + q)$$

where: p_h = horizontal pressure on the wall at depth h (kPa)

K = earth pressure coefficient (see Table 9.1)

γ = unit weight of retained soil (see Table 9.1)

h = depth below top of fill where pressure is computed (m)

q = value of any surcharge (kPa).

For non-draining or partially draining backfill conditions, it is recommended that full hydrostatic pressure be included in the wall design.

In accordance with Clause 6.9.3 of the CHBDC, a compaction surcharge should be added. The magnitude should be 12 kPa at the top of fill and decreasing to 0 kPa at a depth of 2.0 m for Granular B Type I or 1.7 m for Granular A or Granular B Type II. Compaction equipment to be used adjacent to retaining structures should be restricted in accordance with OPSS 501.

Earth pressure coefficients for backfill to the abutment wall are dependent on the material used as backfill. Typical values are shown in Table 9.1.

Table 9.1 – Earth Pressure Coefficients

Wall Condition	Earth Pressure Coefficient (K)					
	OPSS Granular A and Granular B Type II $\phi = 35°, \gamma = 22.8$ kN/m^3		OPSS Granular B Type I $\phi = 32°, \gamma = 21.2$ kN/m^3		Loose to Compact Fill (sand, gravelly sand) $\phi = 30°, \gamma = 20.0$ kN/m^3	
	Horizontal Surface Behind Wall	Sloping Backfill (2H:1V)	Horizontal Surface Behind Wall	Sloping Backfill (2H:1V)	Horizontal Surface Behind Wall	Sloping Backfill (2H:1V)
Active (Unrestrained Wall)	0.27	0.40	0.31	0.48	0.33	0.54
At rest (Restrained Wall)	0.43	-	0.47	-	0.50	-
Passive (Movement towards soil mass)	3.7	-	3.3	-	3.0	-

In conventional design, the use of a material with a high friction angle and low active pressure coefficient (e.g. Granular A, Granular B Type II) might be preferred as it results in lower earth pressures acting on the wall.

The factors in Table 9.1 are “ultimate” values and require certain movements for the respective conditions to be mobilized. The values to be used in design can be estimated from Figure C6.9.1 (a) in the Commentary to the CHBDC.

It is recommended that perforated sub-drains and/or weep holes be installed, where applicable, to provide positive drainage of the granular backfill behind the abutment walls. Reference should be made to OPSD 3102.100.

10 PERMANENT CUT AND FILL

Permanent earth cut is required to widen Shirley Avenue. The earth cut will be formed through up to 6 m of typically loose gravelly sand to sand fill which also contains debris, decayed wood, metal and asphalt fragments. Beyond the fill, the cut would be formed through 1 to 1.5 m of loose to compact sands and silts.

All exposed cut slopes behind the retaining wall from the westerly limit of the wall to the existing fill (approximate Stations 10+510 to 10+590) are expected to be stable at inclinations not steeper than 2H : 1V. Within the existing fill (approximate Stations 10+590 to 10+640), 2H : 1V cut slopes will be stable provided permanent and temporary drainage is provided as discussed below.

It is recommended that all exposed slope surfaces be vegetated and seeded in accordance with current MTO practice and with reference to OPSS 804.

Between approximate Stations 10+590 and 10+640, the base of the cut will be formed at or under the local groundwater level. The exposed very loose sands and silts are permeable, and are prone to disturbance by construction traffic and surface runoff. Temporary site drainage must be provided in this area prior to excavating below the groundwater level (see Section 11 for further details).

Permanent drainage will be required adjacent to the retaining wall within the depressed section of the cut to remove water originating from

- Surface (and storm) runoff and precipitation
- Seepage from the sides and base of the cut

The cohesionless sands and silts encountered at this site are permeable. Consequently, seepage from these soils into the cut will occur. It is recommended that surface runoff and seepage be managed by means of drains and weepholes incorporated behind and through the wall, and connected with sub-drains installed along Shirley Avenue. The sub-drains along Shirley Avenue must be placed at 1.4 m depth or lower under the finished grade and must lead to a positive outlet.

In the area immediately to the west of the random fill and elsewhere, fill placement may be required to raise the grade to the underside of the road pavement. Subgrade preparation, fill selection, placement and compaction requirements should be compatible with the subbase granular materials for the pavement structure.

11 EXCAVATION AND GROUNDWATER CONTROL

Excavations will be required to form the cut for widening of Shirley Avenue and retaining wall construction. All excavations must be carried out in accordance with the Occupational Health and Safety Act (OHSA) and with specific reference to O.Reg. 213/91 for Construction Projects.

Excavation will extend predominantly through the existing fill and the native sands and silts, and possibly reaching the underlying silty clay at some locations. For the purpose of OHSA, the native sands and silts above the groundwater level and the silty clay may be classified as Type 3 soils, and the sands and silts below the groundwater table as Type 4 soils. The gravelly sand to sand fill with debris and other obstructions is classified as Type 3 soil.

All excavations must be carried out in a manner that will not undermine or destabilize the existing slopes and any other existing surface features.

Excavation and backfilling for foundation construction should be carried out with reference to the requirements in OPSS 902.

Water seepage due to perched water in the slope, random fill, surface runoff and precipitation should be expected. For temporary excavations for retaining wall construction at this site, groundwater control will likely be limited to diverting surface runoff and preventing precipitation from entering the excavations supplemented by sump pumping and use of perimeter ditches where required. Filtered sumps must be designed properly so that construction drainage water containing eroded soil and fines do not flow onto the existing roadways. Dewatering systems must be installed and made operational prior to excavating below the groundwater level. It is also important to minimize disturbance of the exposed sand and silt surfaces by limiting construction traffic. Vibratory rollers must not be used for preparation of a sand and silt subgrade. Suggested wording for an NSSP on these issues are included in Appendix F.

The design of the dewatering systems that may be required is the responsibility of the Contractor. The Contract Documents must alert the Contractor of this responsibility and the need to engage a dewatering specialist.

12 ROADWAY PROTECTION

Roadway protection may be required during construction of the retaining walls. An item titled “Protection System” as per OPSS 539 should be included in the contract documents. It is recommended that Performance Level 2 as per Clause 539.04.01.01 and the alignment of the shoring be specified on the contract drawings.

The design of roadway protection should be the responsibility of the Contractor. However, one option that is considered to be suitable for use as temporary shoring at this site is soldier pile and lagging walls. It is anticipated that the soldier piles will need to be installed within the very stiff to hard silty clay, or dense sand and silt at some location, in order to develop the required toe resistance.

A temporary soldier pile and lagging wall may be designed using the parameters given below:

γ	=	20 kN/m^3
γ_w	=	10 kN/m^3 (sands/silts below groundwater)
K_a	=	0.36 (existing fills and loose native sands/silts)
	=	0.33 (silty clay and compact sands/silts)
K_p	=	3.0 (silty clay and compact sands/silts)

The designer of the roadway protection system should check whether the depth of pile is sufficient to provide base fixity.

The actual pressure distribution acting on the shoring system is a function of the construction sequence and the relative flexibility of the wall and these factors must be considered when designing the shoring system. All shoring systems should be designed by a Professional Engineer experienced in such designs.

13 SEISMIC CONSIDERATIONS

The following seismic parameters should be used for design:

- Velocity Related Seismic Zone 0
- Zonal Velocity Ratio 0.05
- Acceleration Related Seismic Zone 1
- Zonal Acceleration Ratio 0.05
- Peak Horizontal Acceleration 0.08g

The soil profile type has been classified as Type I. Therefore, according to Table 4.4.6.1 of the CHBDC, a Site Coefficients "S" (ground motion amplification factor) of 1.0 should be used in seismic design.

In accordance with Clause 4.6.4 of the CHBDC, retaining structures should be designed using active (K_{AE}) and passive (K_{PE}) earth pressure coefficients that incorporate the effects of earthquake loading. The coefficients of horizontal earth pressure for seismic loading presented in Table 13.1 may be used:

Table 13.1 – Earth Pressure Coefficients for Seismic Loading

Earth Pressure Coefficient (K) for Earthquake Loading		
Loading Condition	**OPSS Granular A or Granular B Type II** **ϕ = 35°; γ = 22.8 kN/m^3**	**OPSS Granular B Type I or Type III** **ϕ = 32°; γ = 21.2 kN/m^3**
	Horizontal Surface Behind Wall	**Horizontal Surface Behind Wall**
Active (K_{AE})*	0.3	0.34
Passive (K_{PE})	3.6	3.2
At Rest (K_{OE})**	0.53	0.57

* After Mononobe and Okabe, passive case assumes a horizontal surface in front of the wall.
** After Woods

14 CONSTRUCTION CONCERNS

Potential construction concerns include, but are not necessarily limited to, the following:

- The presence of obstructions in the random fill is possible and could impede installation of deep foundation elements. The Contractor should be made aware of this scenario and be adequately equipped to facilitate deep foundation installation to the design founding elevations.
- Basal instability may be encountered at the load carrying caissons for the contiguous wall. The Contractor will be alerted by an NSSP.
- If excavation/earth cut is carried out in cohesionless soil without prior implementation of adequate measures to control groundwater and surface water, there is a risk that the sides and or base of the excavation will be destabilized. This could lead to a risk to personnel working on site, or to a loss of bearing resistance in the soil. Accordingly, it must be emphasized to the contractor that proper groundwater and surface water control measures must be in place prior to commencing excavation.
- All works carried out by the Contractor must not destabilize the existing slope.
- Existing vegetation is likely having stabilizing effects on the existing slope and should be preserved. Any existing vegetation behind the wall (upslope) that is destroyed or otherwise disturbed must be reinstated after the retaining wall is constructed.

15 CLOSURE

Engineering analysis and preparation of this foundation design report was carried out by Ms. R. Palomeque Reyna.

The report was reviewed by Mr. Sydney Pang, P.Eng., and Mr. P.K. Chatterji, P.Eng., a Designated Principal Contact for MTO Foundations Projects.

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Appendix A

Record of Borehole Sheets

SYMBOLS, ABBREVIATIONS AND TERMS USED ON RECORDS OF BOREHOLES

1. TEXTURAL CLASSIFICATION OF SOILS

CLASSIFICATION	PARTICLE SIZE	VISUAL IDENTIFICATION
Boulders	Greater than 200mm	same
Cobbles	75 to 200mm	same
Gravel	4.75 to 75mm	5 to 75mm
Sand	0.075 to 4.75mm	Not visible particles to 5mm
Silt	0.002 to 0.075mm	Non-plastic particles, not visible to the naked eye
Clay	Less than 0.002mm	Plastic particles, not visible to the naked eye

2. COARSE GRAIN SOIL DESCRIPTION (50% greater than 0.075mm)

TERMINOLOGY	PROPORTION
Trace or Occasional	Less than 10%
Some	10 to 20%
Adjective (e.g. silty or sandy)	20 to 35%
And (e.g. sand and gravel)	35 to 50%

3. TERMS DESCRIBING CONSISTENCY (COHESIVE SOILS ONLY)

DESCRIPTIVE TERM	UNDRAINED SHEAR STRENGTH (kPa)	APPROXIMATE SPT(1) 'N' VALUE
Very Soft	12 or less	Less than 2
Soft	12 to 25	2 to 4
Firm	25 to 50	4 to 8
Stiff	50 to 100	8 to 15
Very Stiff	100 to 200	15 to 30
Hard	Greater than 200	Greater than 30

NOTE: Hierarchy of Soil Strength Prediction

1) Laboratory Triaxial Testing
2) Field Insitu Vane Testing
3) Laboratory Vane Testing
4) SPT value
5) Pocket Penetrometer

4. TERMS DESCRIBING DENSITY (COHESIONLESS SOILS ONLY)

DESCRIPTIVE TERM	SPT "N" VALUE
Very Loose	Less than 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very Dense	Greater than 50

5. LEGEND FOR RECORDS OF BOREHOLES

SYMBOLS AND ABBREVIATIONS FOR SAMPLE TYPE

SS Split Spoon Sample WS Wash Sample AS Auger (Grab) Sample
TW Thin Wall Shelby Tube Sample TP Thin Wall Piston Sample
PH Sampler Advanced by Hydraulic Pressure PM Sampler Advanced by Manual Pressure
WH Sampler Advanced by Self Static Weight RC Rock Core SC Soil Core

$$\text{Sensitivity} = \frac{\text{Undisturbed Shear Strength}}{\text{Remoulded Shear Strength}}$$

▼ Water Level

C_{pen} Shear Strength Determination by Pocket Penetrometer

(1) SPT 'N' Value Standard Penetration Test 'N' Value – refers to the number of blows from a 63.5kg hammer free falling a height of 0.76m to advance a standard 50 mm outside diameter split spoon sampler for 0.3 m depth into undisturbed ground.

(2) DCPT Dynamic Cone Penetration Test – Continuous penetration of a 50 mm outside diameter, 60° conical steel point attached to "A" size rods driven by a 63.5 kg hammer free falling a height of 0.76 m. The resistance to cone penetration is the number of hammer blows required for each 0.3 m advance of the conical point into undisturbed ground.

EXPLANATION OF ROCK LOGGING TERMS

ROCK WEATHERING CLASSIFICATION

Fresh (FR)	No visible signs of weathering.
Fresh Jointed (FJ)	Weathering limited to the surface of major discontinuities.
Slightly Weathered (SW)	Penetrative weathering developed on open discontinuity surfaces, but only slight weathering of rock material.
Moderately Weathered (MW)	Weathering extends throughout the rock mass, but the rock material is not friable.
Highly Weathered (HW)	Weathering extends throughout the rock mass and the rock is partly friable.
Completely Weathered (CW)	Rock is wholly decomposed and in a friable condition, but the rock texture and structure are preserved.

DISCONTINUITY SPACING

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

SYMBOLS

CLAYSTONE

SILTSTONE

SANDSTONE

COAL

BEDROCK

STRENGTH CLASSIFICATION

Rock Strength	**Approximate Uniaxial Compressive Strength (MPa)**	**(psi)**	**Field Estimation of Hardness***
Extremely Strong	Greater than 250	Greater than 36,000	Specimen can only be chipped with a geological hammer
Very Strong	100-250	15,000 to 36,000	Requires many blows of geological hammer to break
Strong	50-100	7,500 to 15,000	Requires more than one blow of geological hammer to break
Medium Strong	25.0 to 50.0	3,500 to 7,500	Breaks under single blow of geological hammer.
Weak	5.0 to 25.0	750 to 3,500	Can be peeled by a pocket knife with difficulty
Very Weak	1.0 to 5.0	150 to 750	Can be peeled by a pocket knife, crumbles under firm blows of geological pick.
Extremely Weak (Rock)	0.25 to 1.0	35 to 150	Indented by thumbnail

TERMS

Total Core Recovery: (TCR)	Core recovered as a percentage of total core run length
Solid Core Recovery:(SCR)	Percent Ratio of solid core of full cylindrical shape recovered. Expressed with respect to the total length of core run
Rock Quality Designation:(RQD)	Total length of sound core recovered in pieces 0.1m in length or larger as a % of total core run length.
Uniaxial Compressive Strength (UCS)	Axial stress required to break the specimen
Fracture Index:(FI)	Frequency of natural fractures per 0.3m of core run.

<u>UNIFIED SOILS CLASSIFICATION</u>

MAJOR DIVISIONS		GROUP SYMBOL	TYPICAL DESCRIPTION
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW	Well-graded gravels or gravel-sand mixtures, little or no fines.
		GP	Poorly-graded gravels or gravel-sand mixtures, little or no fines.
		GM	Silty gravels, gravel-sand-silt mixtures.
		GC	Clayey gravels, gravel-sand-clay mixtures.
	SAND AND SANDY SOILS	SW	Well-graded sands or gravelly sands, little or no fines.
		SP	Poorly-graded sands or gravelly sands, little or no fines.
		SM	Silty sands, sand-silt mixtures.
		SC	Clayey sands, sand-clay mixtures.
FINE GRAINED SOILS	SILTS AND CLAYS $W_L < 50\%$	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. ($W_L < 30\%$).
		CI	Inorganic clays of medium plasticity, silty clays. ($30\% < W_L < 50\%$).
		OL	Organic silts and organic silty-clays of low plasticity.
	SILTS AND CLAYS $W_L > 50\%$	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
		CH	Inorganic clays of high plasticity, fat clays.
		OH	Organic clays of medium to high plasticity, organic silts.
HIGHLY ORGANIC SOILS		Pt	Peat and other highly organic soils.
CLAY SHALE			
SANDSTONE			
SILTSTONE			
CLAYSTONE			
COAL			

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RECORD OF BOREHOLE No 14-501

METRIC

GWP# 3104-15-00
LOCATION Sta. 10+500 10m RT CL Retaining Wall N 4 814 582.8 E 226 623.9
ORIGINATED BY AN
HWY Shirley Ave.
BOREHOLE TYPE Hollow Stem Augers
COMPILED BY AN
DATUM Geodetic
DATE 2015.01.12 - 2015.01.12
CHECKED BY RPR

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
322.6	GROUND SURFACE
0.0 / 0.1	**TOPSOIL:** (50mm)
	SAND and **SILT**, trace to some clay, pockets of clay, occasional rootlets and organics Loose to Compact Dark Brown to Brown Moist Wet Dense Very Dense
318.0 / 4.6	Silty **CLAY**, trace sand Hard Brown Moist
315.4 / 7.2	**SAND**, some silt, trace clay Dense Grey Moist Very Dense Wet
312.8 / 9.8	END OF BOREHOLE AT 9.8m.

Continued Next Page

SAMPLES

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR	SA	SI	CL
1	SS	6				
2	SS	12	0	38	48	14
3	SS	15				
4	SS	31	0	45	52	3
5	SS	55				
6	SS	47				
7	SS	35	0	5	36	59
8	SS	41	0	79	17	4
9	SS	70				

GROUND WATER CONDITIONS

ELEVATION SCALE: 322, 321, 320, 319, 318, 317, 316, 315, 314, 313

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/m^3

+ 3, × 3: Numbers refer to Sensitivity

20 / 15 / 5 / 10 (%) STRAIN AT FAILURE

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RECORD OF BOREHOLE No 14-501

METRIC

GWP#	3104-15-00	LOCATION	Sta. 10+500 10m RT CL Retaining Wall N 4 814 582.8 E 226 623.9	ORIGINATED BY	AN
HWY	Shirley Ave.	BOREHOLE TYPE	Hollow Stem Augers	COMPILED BY	AN
DATUM	Geodetic	DATE	2015.01.12 - 2015.01.12	CHECKED BY	RPR

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/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES						
	Continued From Previous Page										
	Piezometer installation consists of 25mm diameter Schedule 40 PVC pipe with a 1.52m slotted screen.										

WATER LEVEL READINGS:

DATE	DEPTH (m)	ELEV. (m)
Jan. 21/ 15	4.9	317.7
Mar. 13/ 15	4.7	317.9

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

15 20 5 10 (%) STRAIN AT FAILURE

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Ontario

THURBER

RECORD OF BOREHOLE No 14-502

METRIC

GWP# 3104-15-00
LOCATION Sta. 10+560 10m RT CL Retaining Wall N 4 814 602.8 E 226 674.9
ORIGINATED BY AN/ES
HWY Shirley Ave.
BOREHOLE TYPE Hollow Stem Augers
COMPILED BY AN
DATUM Geodetic
DATE 2015.01.12 - 2015.01.12
CHECKED BY RPR

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	GR	SA	SI	CL
322.6	GROUND SURFACE								
0.0	**TOPSOIL:** (50mm)								
	SAND and **SILT**, trace clay, occasional roots and organics Loose to Compact Brown Frozen/Wet	1	SS	5					
		2	SS	10					
		3	SS	26		0	34	59	7
320.2 2.4	Silty **CLAY**, trace sand and gravel Very Stiff to Hard Brown Moist	4	SS	22					
		5	SS	31					
		6	SS	31		0	0	43	57
		7	SS	32					
		8	SS	31		0	0	33	67
313.6 9.0	**SAND**, some silt, trace clay, trace gravel Very Dense Grey Wet	9	SS	50					
312.8 9.8	END OF BOREHOLE AT 9.8m.								

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; GROUND WATER CONDITIONS; ELEVATION SCALE (322, 321, 320, 319, 318, 317, 316, 315, 314, 313); 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 (%)

Continued Next Page

+ ³, × ³: Numbers refer to Sensitivity

20 15 5 10 (%) STRAIN AT FAILURE

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No 14-502

METRIC

GWP#	3104-15-00	LOCATION	Sta. 10+560 10m RT CL Retaining Wall N 4 814 602.8 E 226 674.9	ORIGINATED BY	AN/ES
HWY	Shirley Ave.	BOREHOLE TYPE	Hollow Stem Augers	COMPILED BY	AN
DATUM	Geodetic	DATE	2015.01.12 - 2015.01.12	CHECKED BY	RPR

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 (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES						
	Continued From Previous Page										
	BOREHOLE BACKFILLED WITH BENTONITE HOLEPLUG AND AUGER CUTTINGS TO SURFACE.										

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

20 / 15 ◐ 5 / 10 (%) STRAIN AT FAILURE

ONTMT4S 19-5161-191.GPJ 2015TEMPLATE(MTO).GDT 6/28/16

RECORD OF BOREHOLE No 14-503

METRIC

GWP# 3104-15-00 | LOCATION Sta. 10+625 12m RT CL Retaining Wall N 4 814 617.9 E 226 730.8 | ORIGINATED BY SDP

HWY Shirley Ave. | BOREHOLE TYPE Hollow Stem Augers | COMPILED BY AN

DATUM Geodetic | DATE 2015.01.08 - 2015.01.08 | CHECKED BY RPR

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	REMARKS	GR	SA	SI	CL
326.4	GROUND SURFACE									
0.0	**ASPHALT:**(200mm)									
0.2	Gravelly **SAND** to **SAND**, some gravel, some silt to silty, some clay, occasional debris, decayed wood, metal and asphalt fragments, clay pockets Compact to Loose Brown Moist (FILL)	1	SS	30	326		22	44	23	11
		2	SS	8						
		3	SS	6	325					
	Odour, occasional rootlets Dark Brown	4	SS	4	324	Photo-ionization detector (P.I.D.) measurements less than 10ppm.				
		5	SS	5	323					
	Clay pockets	6	SS	12	322 (groundwater level)		15	46	25	14
320.8 / 5.6	**SAND**, trace to some silt, trace gravel, trace clay Very Loose Brown Wet	7	SS	2	321, 320					
319.2 / 7.2	**SAND** and **SILT**, mixed with organics, some clay, trace gravel, odour, occasional roots and rootlets Very Loose Dark Brown to Black Wet	8	SS	2	319		0	54	34	12
	Layer of sand (300mm) at 8.8m				318					
317.3 / 9.1	Silty **CLAY** Stiff Grey Moist	9	SS	14	317					

Plot 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); UNIT WEIGHT γ kN/m^3; REMARKS & GRAIN SIZE DISTRIBUTION (%); STRAT PLOT; GROUND WATER CONDITIONS.

Continued Next Page

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

20 / 15 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 14-503

METRIC

GWP# 3104-15-00 LOCATION Sta. 10+625 12m RT CL Retaining Wall N 4 814 617.9 E 226 730.8 ORIGINATED BY SDP
HWY Shirley Ave. BOREHOLE TYPE Hollow Stem Augers COMPILED BY AN
DATUM Geodetic DATE 2015.01.08 - 2015.01.08 CHECKED BY RPR

ELEV / DEPTH	SOIL PROFILE: DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100) / SHEAR STRENGTH kPa (○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × 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
	Continued From Previous Page										
	Silty **CLAY** Very Stiff Grey Moist						316				
			10	SS	26						0 0 42 58
							315				
			11	SS	21		314				
313.6 / 12.8	END OF BOREHOLE AT 12.8m. Piezometer installation consists of 19mm diameter Schedule 40 PVC pipe with a 3.0m slotted screen.										

WATER LEVEL READINGS:

DATE	DEPTH (m)	ELEV. (m)
Jan. 21/ 15	4.5	321.8

ONTMT4S 19-5161-191.GPJ 2015TEMPLATE(MTO).GDT 6/28/16

+ 3, × 3: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

RECORD OF BOREHOLE No 16-01

METRIC

GWP# 3104-15-00 | LOCATION Retaining Wall N 4 814 607.6 E 226 718.6 | ORIGINATED BY AN
HWY Shirley Ave. | BOREHOLE TYPE Hollow Stem Augers | COMPILED BY AN
DATUM Geodetic | DATE 2016.03.02 - 2016.03.02 | CHECKED BY SKP

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
326.9	GROUND SURFACE					
0.0	Sandy **GRAVEL**, some silt, trace clay, odour Compact Black to Brown Moist (FILL)	1	SS	27		
326.2 0.7	Silty **SAND**, some to trace gravel Compact to Very Loose Grey Moist (FILL)	2	SS	17	326	
		3	SS	7	325	
		4	SS	9		4 51 30 15
		5	SS	7	324	
		6	SS	4	323	
		7	SS	0	322	
		8	SS	0	321	
					320	
319.3 7.6	Silty **SAND**, trace gravel Compact Light Brown Wet	9	SS	15	319	
318.5 8.4	Silty **CLAY** Very Stiff Grey Moist				318	
		10	SS	18	317	0 0 53 47

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

Continued Next Page

+ 3, × 3: Numbers refer to Sensitivity   20 / 15 ⊕ 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 16-01

METRIC

GWP#	3104-15-00	LOCATION	Retaining Wall N 4 814 607.6 E 226 718.6	ORIGINATED BY	AN
HWY	Shirley Ave.	BOREHOLE TYPE	Hollow Stem Augers	COMPILED BY	AN
DATUM	Geodetic	DATE	2016.03.02 - 2016.03.02	CHECKED BY	SKP

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 (%) GR SA SI CL

Continued From Previous Page

ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Silty **CLAY**, trace sand Very Stiff Grey Moist		11	SS	24	316	
			12	SS	19	315	0 0 46 54
	Probable cobble		13	SS	18	314 / 313	
312.4 14.5	Stiff		14	SS	13	312 / 311	
310.1 16.8	**SAND** and **SILT**, trace gravel, some clay Compact Grey Wet		15	SS	15	310	6 35 47 12
309.2 17.7	**SAND**, trace gravel, trace silt Compact Grey Moist		16	SS	24	309	
			17	SS	17	308	Split spoon sampler wet
			18	SS	100*	307	Split spoon sampler possibly full 0 91 9 (SI+CL)

Continued Next Page

+ ³, × ³: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 16-01

METRIC

GWP# 3104-15-00 | LOCATION Retaining Wall N 4 814 607.6 E 226 718.6 | ORIGINATED BY AN

HWY Shirley Ave. | BOREHOLE TYPE Hollow Stem Augers | COMPILED BY AN

DATUM Geodetic | DATE 2016.03.02 - 2016.03.02 | CHECKED BY SKP

ELEV DEPTH	DESCRIPTION (Continued From Previous Page)	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/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR	SA	SI	CL
306.5 20.4	Silty **CLAY** Hard Grey Moist						306							
			19	SS	66				○		0	0	46	54
305.3 21.6	END OF BOREHOLE AT 21.6m. BOREHOLE BACKFILLED WITH BENTONITE HOLEPLUG AND AUGER CUTTINGS TO SURFACE.													

+ 3, × 3: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 16-02

METRIC

GWP# 3104-15-00 | LOCATION Retaining Wall N 4 814 617.9 E 226 753.6 | ORIGINATED BY AN

HWY Shirley Ave. | BOREHOLE TYPE Hollow Stem Augers | COMPILED BY AN

DATUM Geodetic | DATE 2016.03.03 - 2016.03.03 | CHECKED BY SKP

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

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	REMARKS / GR SA SI CL
326.3	GROUND SURFACE					
0.0 / 326.0 / 0.3	**TOPSOIL**, trace rootlets, Soft, Brown, Moist	1	SS	5	326	
	Silty **SAND**, trace to some gravel, trace rootlets, Loose to Very Loose, Brown, Moist (FILL)	2	SS	9	325	
		3	SS	6		15 55 25 5; Split spoon sampler wet
324.1 / 2.2	Compact	4	SS	15	324	
323.3 / 3.0	Probable cobbles and boulders, Dense	5	SS	41	323	
	Wet	6	SS	3	322	
	Wood chips and organics	7	SS	5	321	10 56 23 11
	Trace clay	8	SS	7	320	
					319	
318.5 / 7.8 / 318.2 / 8.1	Silty **SAND**, Compact, Brown, Wet	9	SS	14	318	
	Silty **CLAY**, trace sand, Very Stiff, Brown, Moist	10	SS	17	317	

Continued Next Page

+³, ×³: Numbers refer to Sensitivity

20 / 15 ⊕ 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No 16-02

METRIC

GWP#	3104-15-00	LOCATION	Retaining Wall N 4 814 617.9 E 226 753.6	ORIGINATED BY	AN
HWY	Shirley Ave.	BOREHOLE TYPE	Hollow Stem Augers	COMPILED BY	AN
DATUM	Geodetic	DATE	2016.03.03 - 2016.03.03	CHECKED BY	SKP

Continued From Previous Page

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	GR	SA	SI	CL	REMARKS
	Silty **CLAY**, trace sand Very Stiff Grey Moist				316						
		11	SS	15			0	0	50	50	
					315						
					314						
		12	SS	21							
					313						
		13	SS	19							
					312						
					311						
		14	SS	15			0	0	33	67	
310.0 16.3	**SAND** and **SILT**, trace to some clay, trace gravel Compact to Very Dense Grey Moist				310						
		15	SS	25							
					309						
					308						
	Probable cobbles	16	SS	90/ 0.225			7	36	48	9	
					307						
306.3											Resistance to augering

Continued Next Page

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; GROUND WATER CONDITIONS; 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 (%)

+ ³, × ³: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 16-02

METRIC

GWP# 3104-15-00 | LOCATION Retaining Wall N 4 814 617.9 E 226 753.6 | ORIGINATED BY AN

HWY Shirley Ave. | BOREHOLE TYPE Hollow Stem Augers | COMPILED BY AN

DATUM Geodetic | DATE 2016.03.03 - 2016.03.03 | CHECKED BY SKP

ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100) / SHEAR STRENGTH kPa (○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L — WATER CONTENT (%) 20 40 60	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
	Continued From Previous Page													
20.0	Silty **CLAY**, trace sand Hard Grey Wet		17	SS	88		306							
							305							
304.5			18	SS	78						0	9	39	52
21.8	END OF BOREHOLE AT 21.8m. Piezometer installation consists of 25mm diameter Schedule 40 PVC pipe with a 4.57m slotted screen. WATER LEVEL READINGS: DATE DEPTH (m) ELEV. (m) Mar. 09/ 16 8.5 317.8													

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

20 / 15 ◐ 5 / 10 (%) STRAIN AT FAILURE

Appendix B

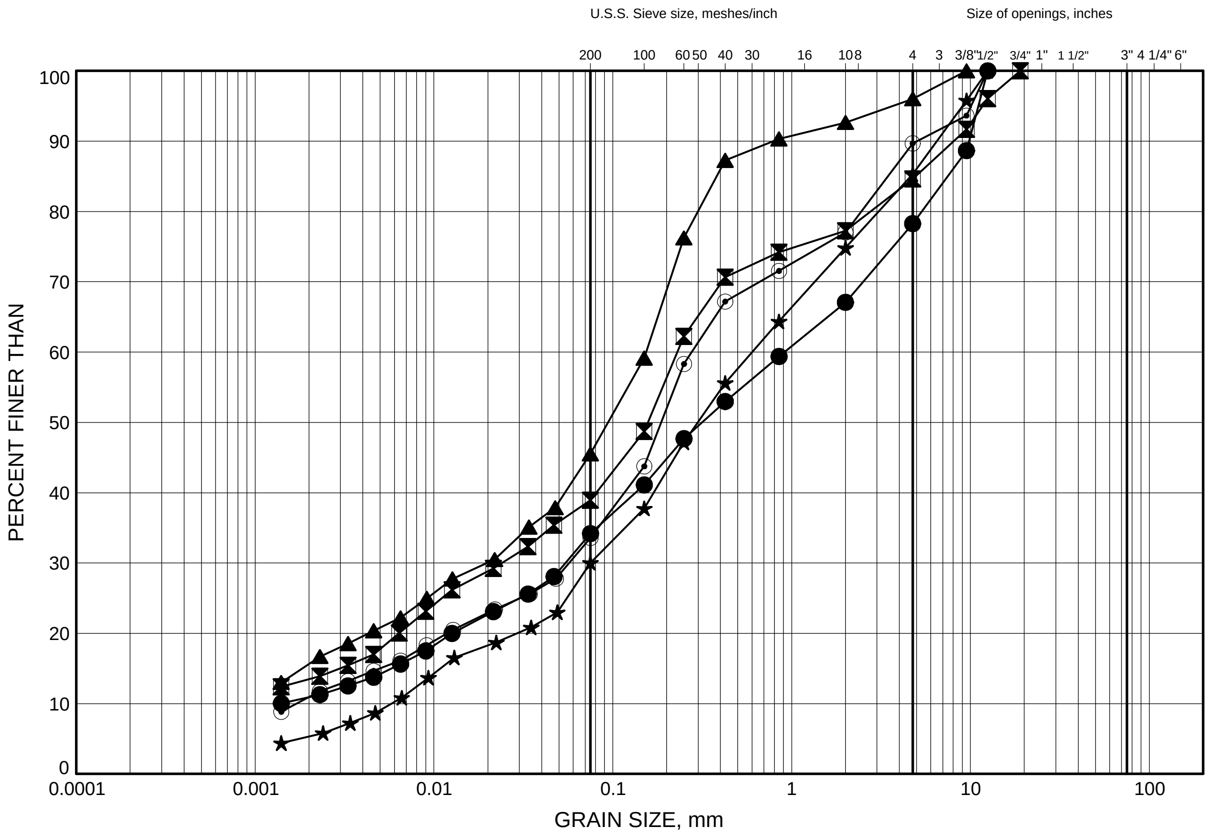
Laboratory Test Results

Shirley Ave. Widening

GRAIN SIZE DISTRIBUTION

FIGURE B1

Gravelly SAND to Silty SAND FILL



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	14-503	0.46	325.94
⧗	14-503	4.88	321.52
▲	16-01	2.59	324.31
★	16-02	1.83	324.47
⊙	16-02	4.88	321.42

Date June 2016

GWP# 3104-15-00

THURBER

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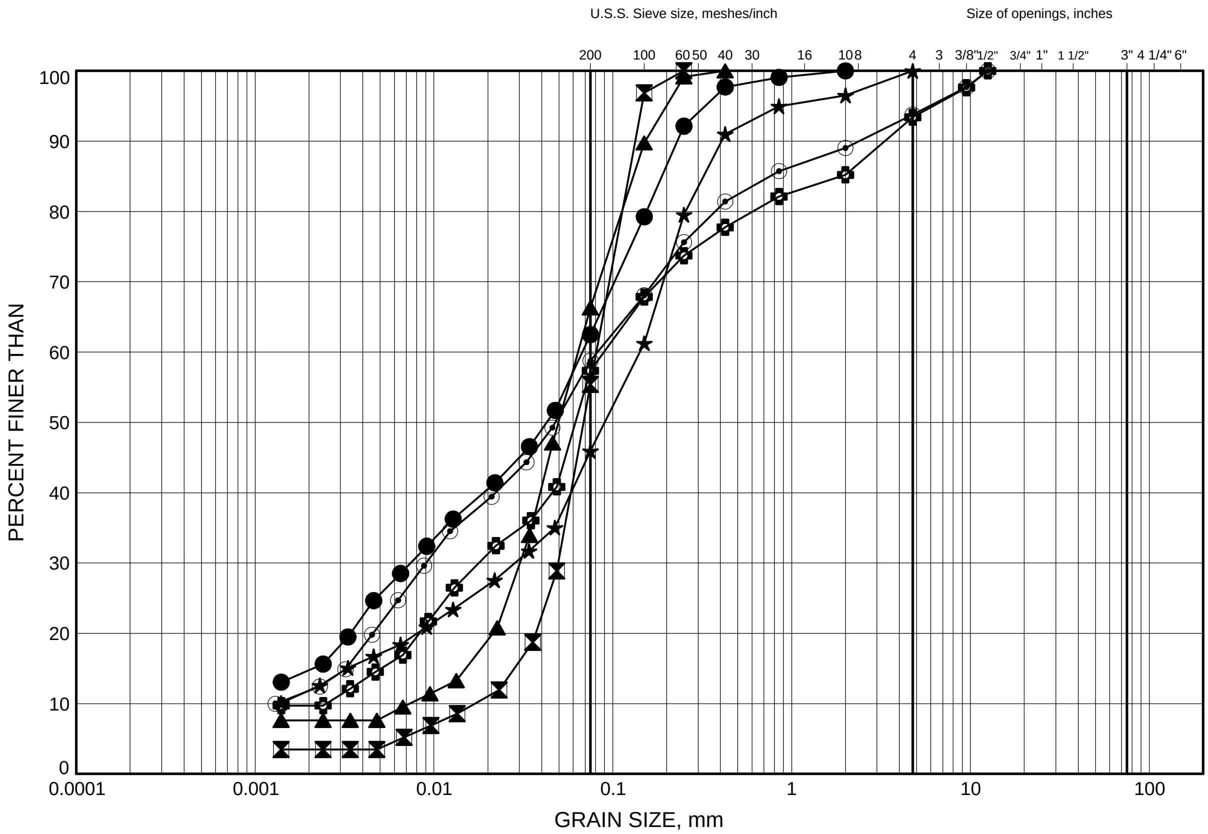
Shirley Ave. Widening

GRAIN SIZE DISTRIBUTION

FIGURE B2

SAND and SILT



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	14-501	1.07	321.53
⧗	14-501	2.59	320.01
▲	14-502	1.83	320.77
★	14-503	7.92	318.48
⊙	16-01	16.76	310.14
✿	16-02	18.48	307.82

GRAIN SIZE DISTRIBUTION - THURBER 19-5161-191.GPJ 6/28/16

Date June 2016

GWP# 3104-15-00

THURBER

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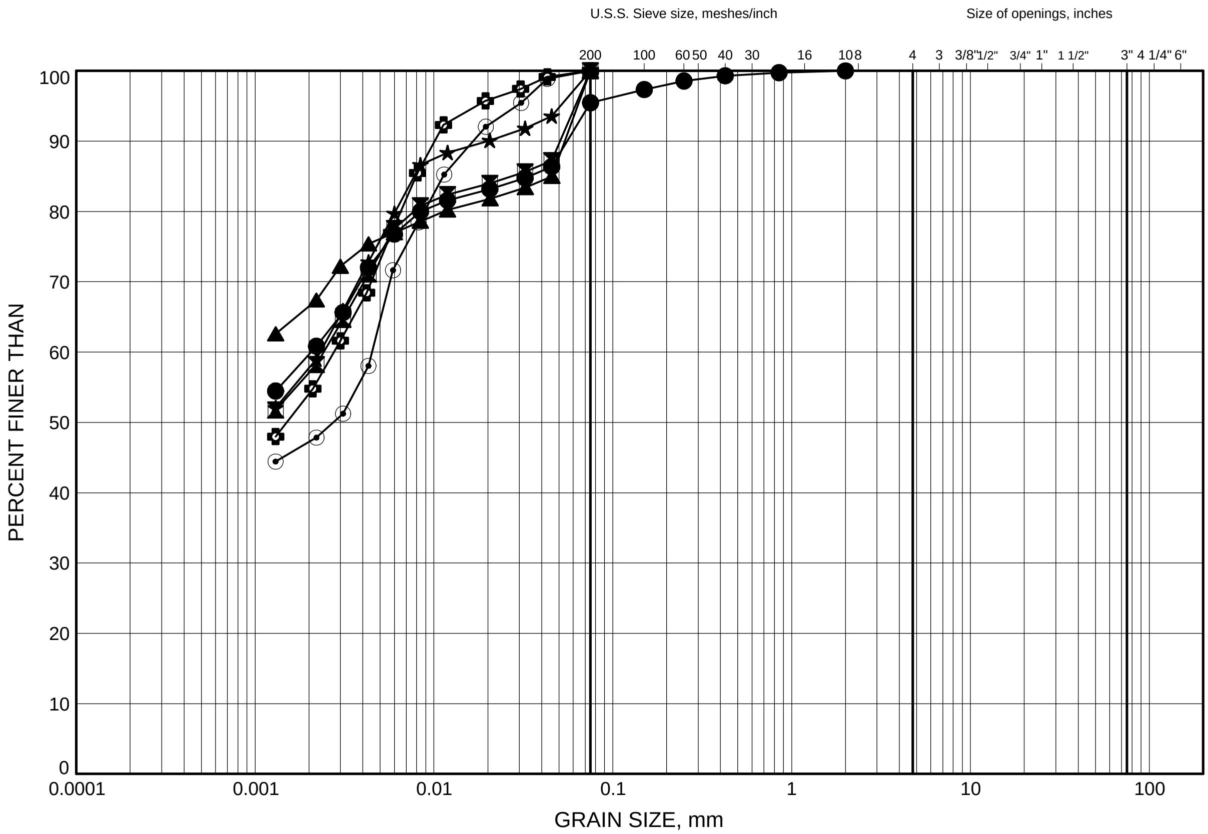
Shirley Ave. Widening GRAIN SIZE DISTRIBUTION	FIGURE B3

Silty CLAY



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	14-501	6.40	316.20
⧗	14-502	4.88	317.72
▲	14-502	7.92	314.68
★	14-503	10.97	315.43
⊙	16-01	9.14	317.76
✿	16-01	12.19	314.71

Date June 2016
GWP# 3104-15-00

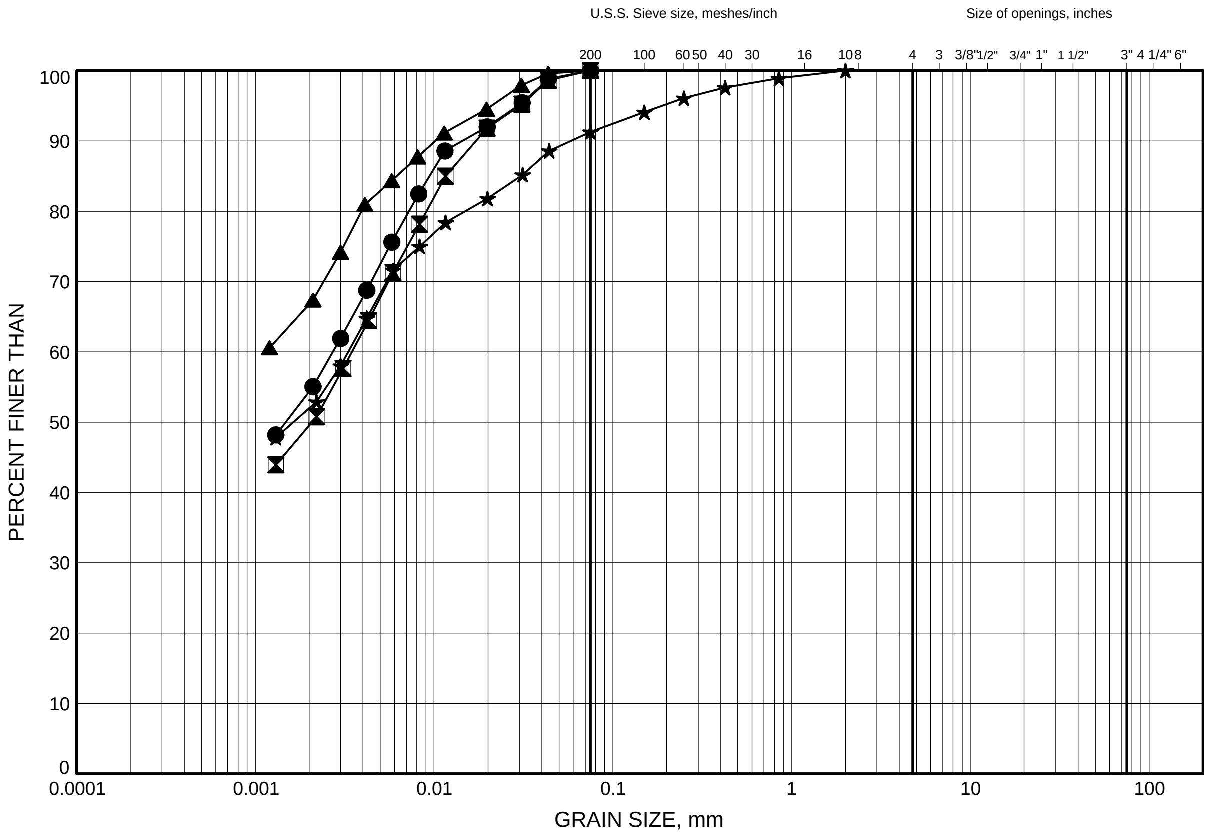
THURBER

Prep'd AN
Chkd. SKP

GRAIN SIZE DISTRIBUTION - THURBER 19-5161-191.GPJ 6/28/16

Shirley Ave. Widening GRAIN SIZE DISTRIBUTION	FIGURE B4

Silty CLAY



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	16-01	21.34	305.56
⧗	16-02	10.97	315.33
▲	16-02	15.54	310.76
★	16-02	21.56	304.74

Date June 2016

GWP# 3104-15-00

THURBER

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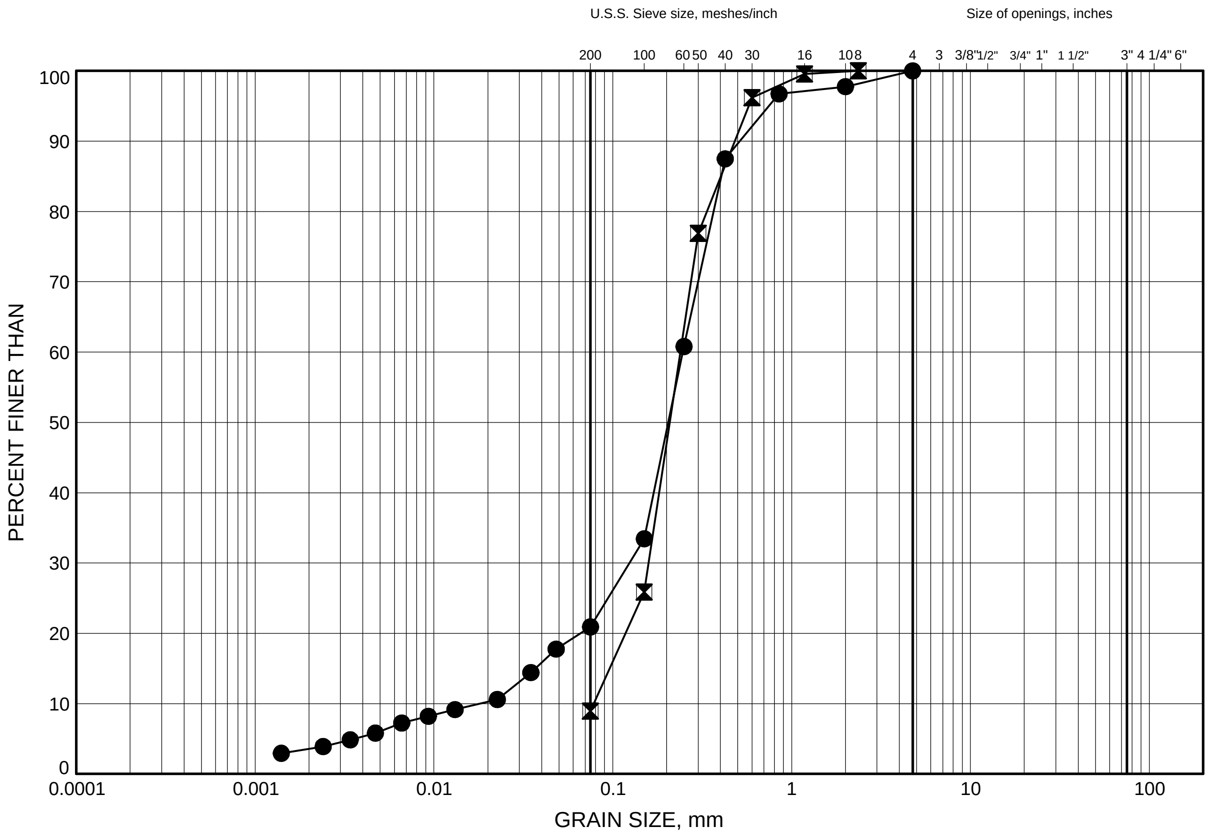
Shirley Ave. Widening

GRAIN SIZE DISTRIBUTION

FIGURE B5

SAND



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	14-501	7.92	314.68
⧗	16-01	19.74	307.16

GRAIN SIZE DISTRIBUTION - THURBER 19-5161-191.GPJ 6/28/16

Date June 2016

GWP# 3104-15-00

THURBER

Prep'd AN

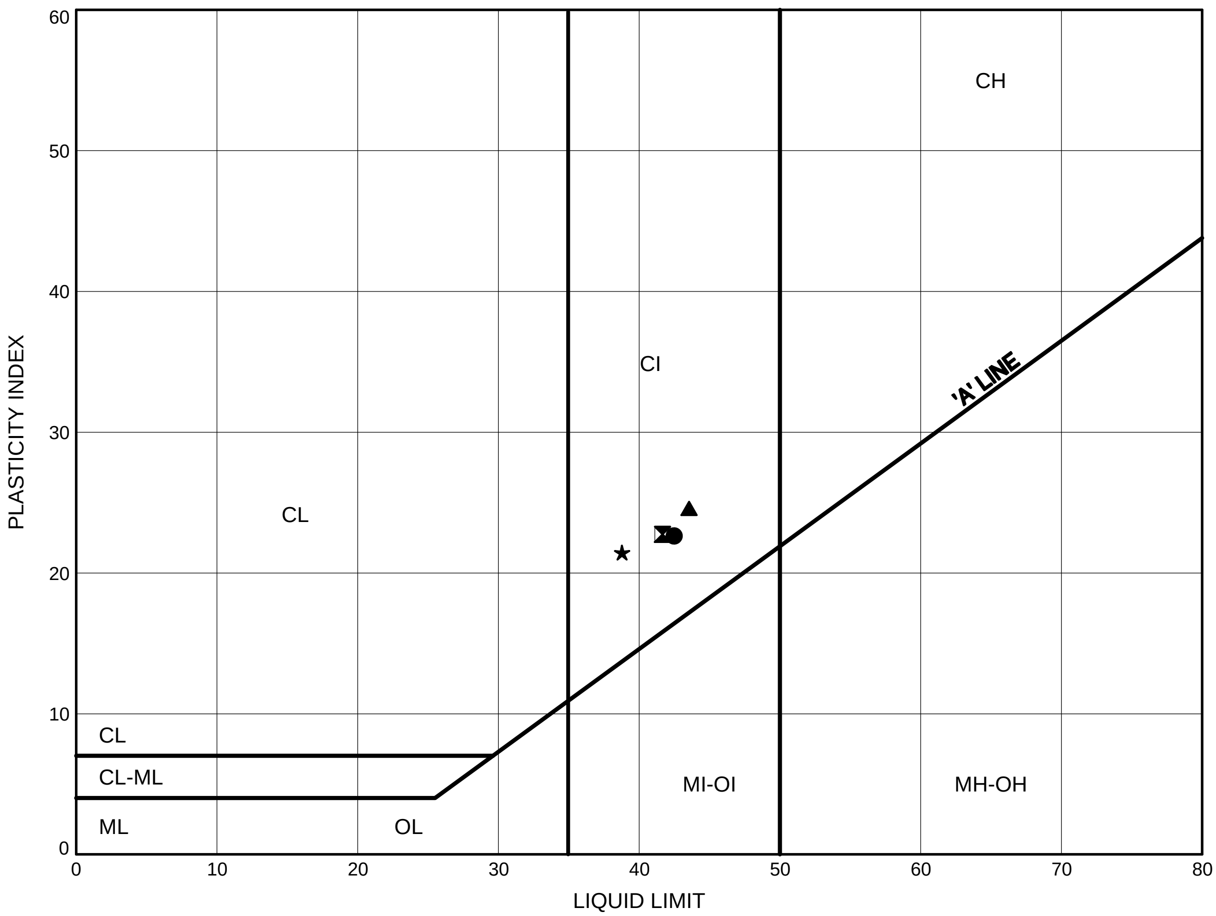
Chkd. SKP

Shirley Ave. Widening

ATTERBERG LIMITS TEST RESULTS

FIGURE B6

Silty CLAY



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	14-501	6.40	316.20
⧗	14-502	4.88	317.72
▲	14-502	7.92	314.68
★	14-503	10.97	315.43

Date June 2016

GWP# 3104-15-00

THURBER

Prep'd AN

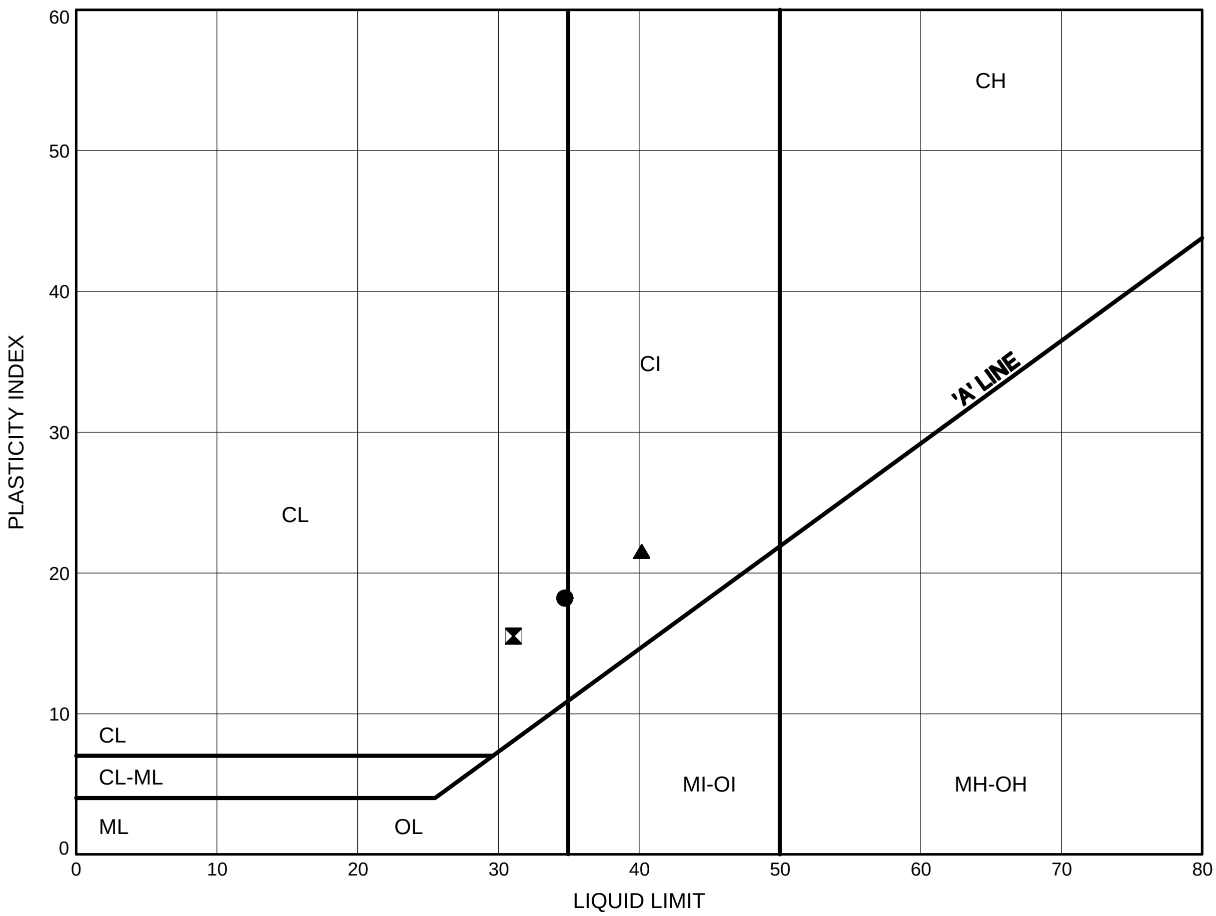
Chkd. SKP

Shirley Ave. Widening

ATTERBERG LIMITS TEST RESULTS

FIGURE B7

Silty CLAY



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	16-01	12.19	314.71
⧗	16-02	10.97	315.33
▲	16-02	15.54	310.76

THURBALT 19-5161-191.GPJ 6/28/16

Date June 2016

GWP# 3104-15-00

THURBER

Prep'd AN

Chkd. SKP

Appendix C

Drawings titled "Borehole Locations and Soil Strata"

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

CONT No 2016-3009
GWP No 3104-15-00

SHIRLEY AVENUE WIDENING
RETAINING WALL
BOREHOLE LOCATIONS AND SOIL STRATA

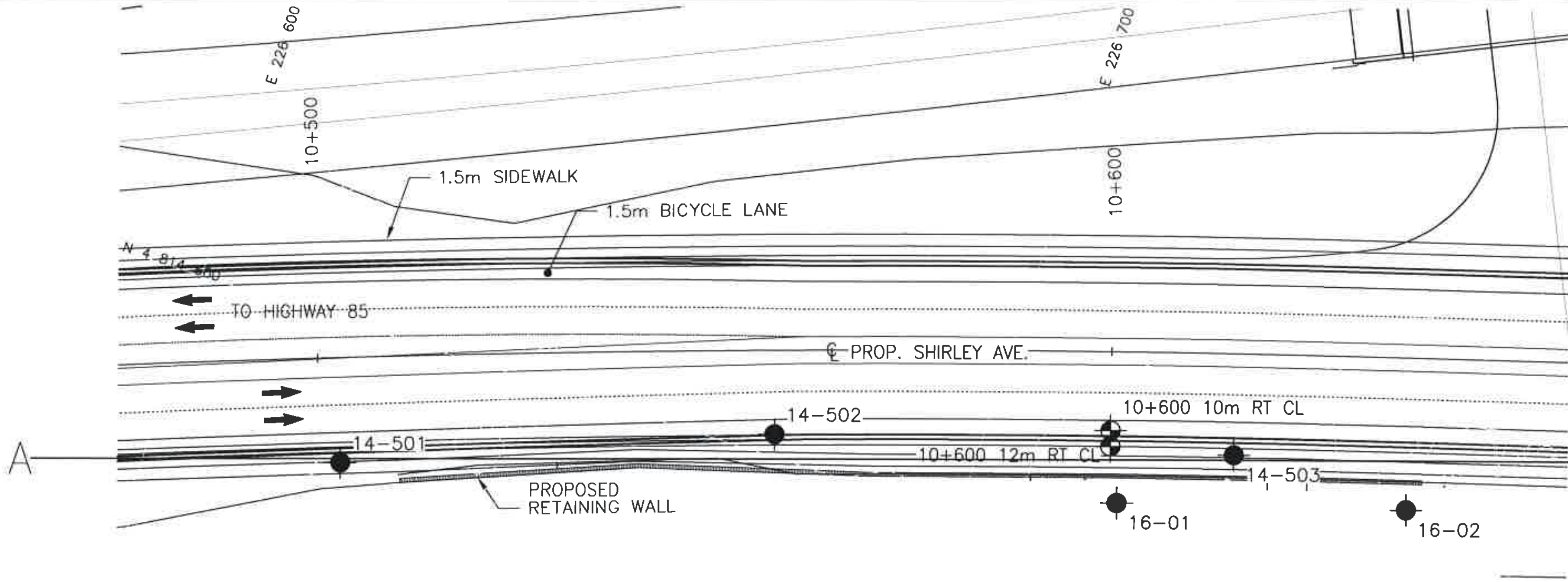
SHEET 126

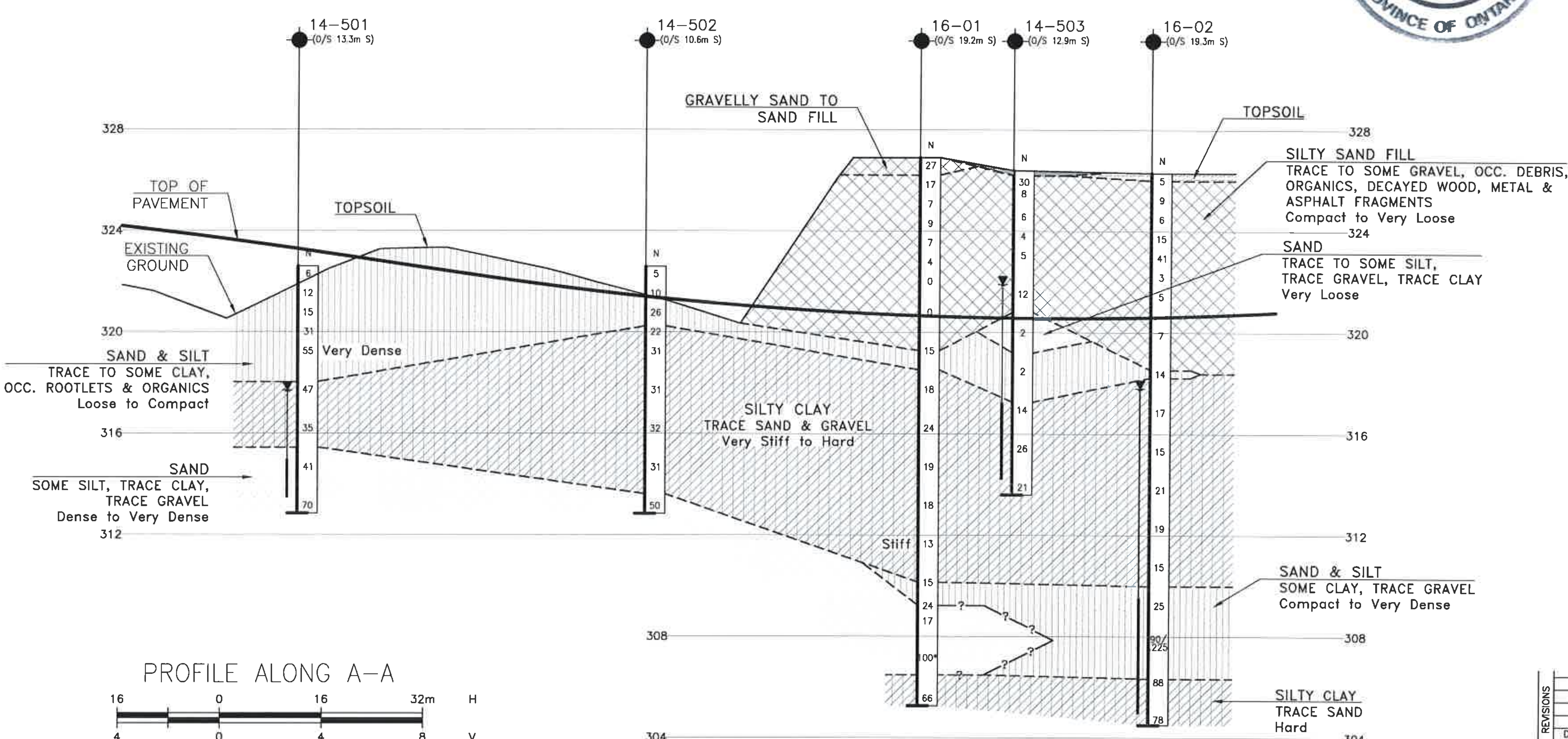
MMM GROUP

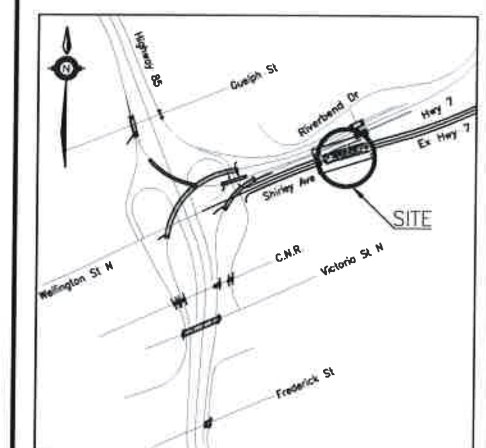
THURBER ENGINEERING LTD

LICENSED PROFESSIONAL ENGINEER
P. K. CHATTERJI
July 4/16
PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER
G. PANG
July 4/16
PROVINCE OF ONTARIO







KEYPLAN

LEGEND

⌖	Borehole
⌖	Pavement Borehole
N	Blows /0.3m (Std Pen Test, 475J/blow)
CONE	Blows /0.3m (60° Cone, 475J/blow)
PH	Pressure, Hydraulic
⊻	Water Level
⊻	Head Artesian Water
	Piezometer
90%	Rock Quality Designation (RQD)
A/R	Auger Refusal

NO	ELEVATION	NORTHING	EASTING
14-501	322.6	4 814 582.8	226 623.9
14-502	322.6	4 814 602.8	226 674.9
14-503	326.4	4 814 617.9	226 730.8
16-01	326.9	4 814 607.6	226 718.6
16-02	326.3	4 814 617.9	226 753.6

-NOTES-

1) The boundaries between soil strata have been established only at Borehole locations. Between Boreholes the boundaries are assumed from geological evidence.
2) This drawing is for subsurface information only. Surface details and features are for conceptual illustration.

GEOCRES No. 40P8-233

REVISIONS	DATE	BY	DESCRIPTION

DESIGN RPR	CHK SKP	CODE	LOAD	DATE JUN 2016
DRAWN AN	CHK RPR	SITE 33-546/W	STRUCT	DWG 2

FILENAME: H:\Drafting\19\5161\191\ted1191-Plan&Profile(ShirleyAve.).dwg
PLOTDATE: 6/30/2016 10:00 AM

MINISTRY OF TRANSPORTATION, ONTARIO

Appendix D

Site Photographs

Photo 1 Borehole 14-501, Approximate Station 10+500

Photo 2 Borehole 14-502, Approximate Station 10+560, looking north

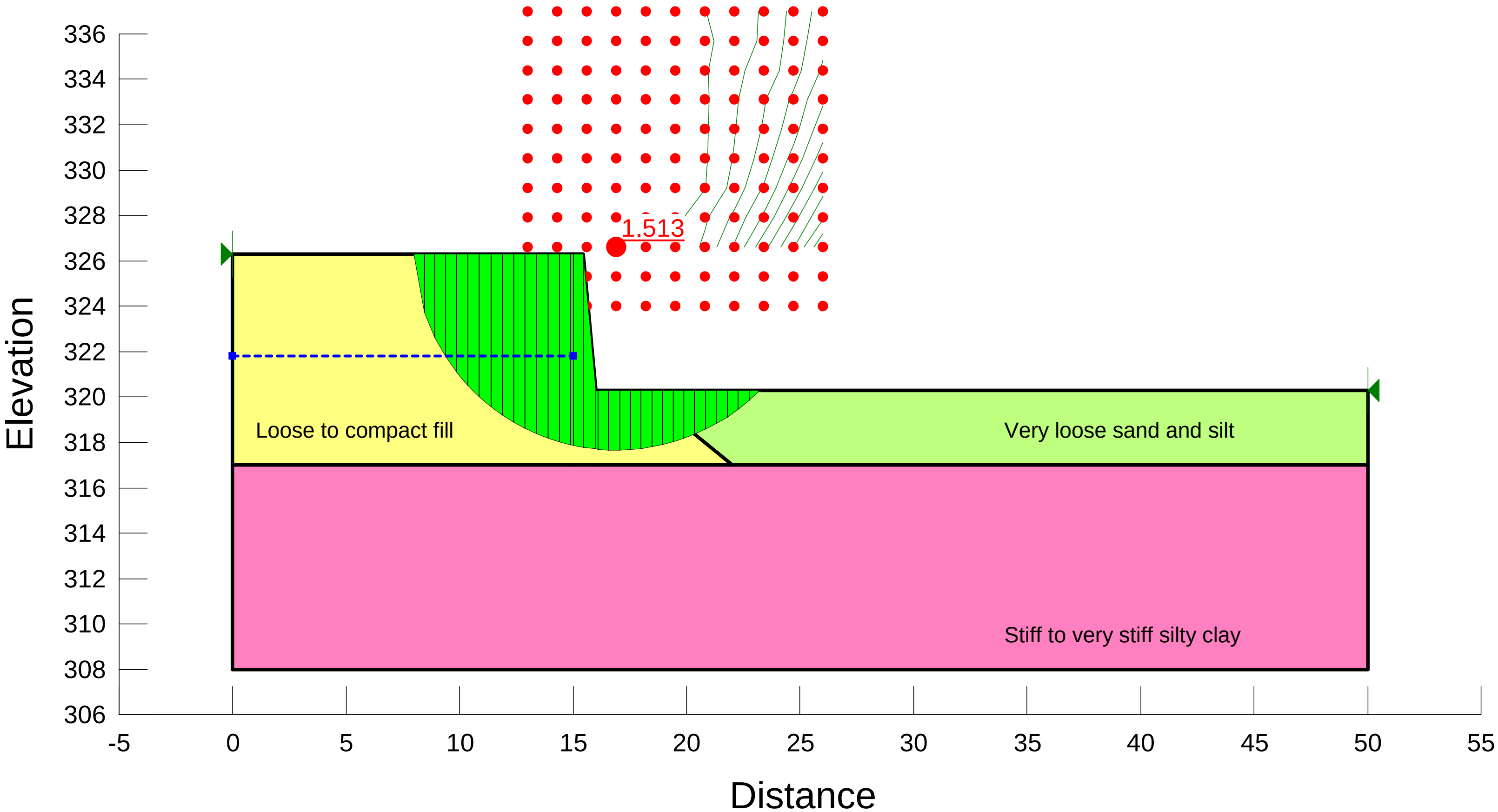
Photo 3 Shirley Avenue Centreline, Station 10+600

Appendix E

Selected Stability Analysis Results

19-5161-191
Shirley Avenue
Retaining Wall
Maximum retaining wall height 6.0 m
Approximate Station 10+625
Drained analysis

Loose to compact fill	20 kN/m³	0 kPa	30 °	1
Very loose sand and silt	19 kN/m³	0 kPa	28 °	1
Stiff to very stiff silty clay	20 kN/m³	5 kPa	30 °	1
Retaining wall	0.01 kN/m³	300 kPa	45 °	1



5/14/2015
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Figure E1

19-5161-191
Shirley Avenue
Retaining Wall
Maximum retaining wall height 6.0 m
Approximate Station 10+625
Undrained analysis

Loose to compact fill	20 kN/m³	0 kPa	30 °	1
Very loose sand and silt	19 kN/m³	0 kPa	28 °	1
Stiff to very stiff silty clay	20 kN/m³	90 kPa	0 °	1
Retaining wall	0.01 kN/m³	300 kPa	45 °	1

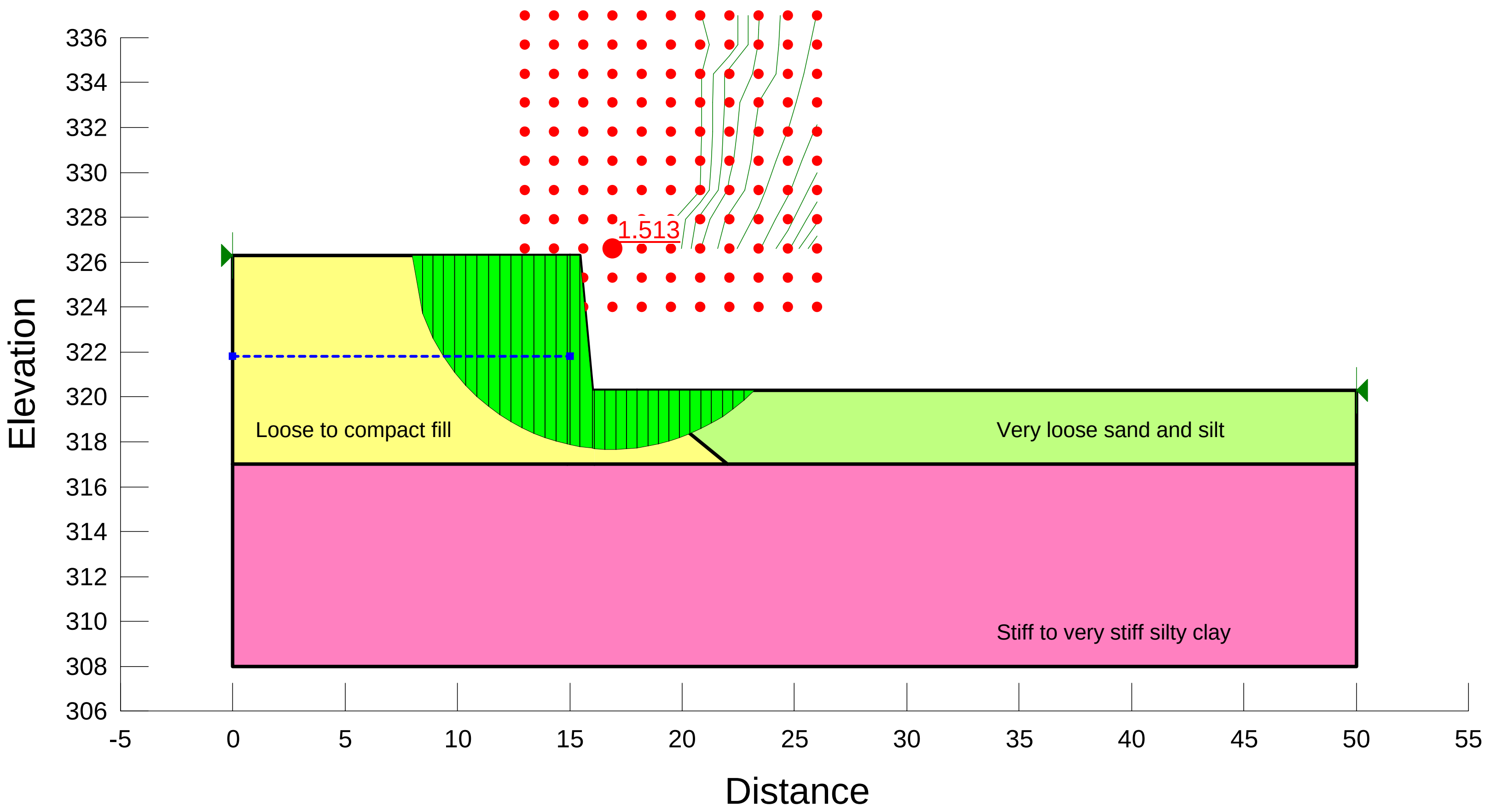

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Figure E2

Appendix F

List of OPSS and OPSD Documents and NSSP Wording

1. List of OPSS and OPSD Documents Referenced in this Report

OPSS 539

OPSS 804

OPSS 902

OPSS 903

OPSS.PROV 1010

OPSD 3101.150

OPSD 3102.100

2. Suggested Text for NSSP on "Drilling of Caissons"

Installation of caissons for the caisson wall may encounter debris, concrete, plywood, metal, and other materials including oversized obstructions within the fill. The caisson installation equipment must be capable of handling, dislodging and removing such obstructions to facilitate caisson installation.

Construction of caissons will require the use of temporary steel liners to support the caisson sidewalls and to provide seepage cut-off. A balancing head of water and/or slurry will need to be used inside the deeper caissons between approximate Stations 10+590 and 10+640 in order to minimize the risk of basal instability. Such balancing water and/or slurry may also be required in other caissons. Concrete should be placed with a minimum delay after each caisson is drilled, cleaned and inspected. Where water remains in the hole, tremie techniques shall be used to place concrete inside the caisson hole. Where a balancing head of water or slurry is not used and the accumulated water can be pumped dry, conventional gravity method may be used to place the concrete.

3. Suggested Text for NSSP on "Pile Installation"

The existing random fill from approximate Stations 10+590 to 10+640 may contain obstructions which could interfere with or obstruct pile installation operations. The piles should initially be driven without tip reinforcement. Should there be obstructions that impede pile penetration and in order to minimize pile damage while driving through potential rubble, debris, boulders, cobbles and harder/dense zones to achieve the required tip elevations and soil resistance, the remaining pile tips may then be reinforced with driving shoes such as the Titus Standard Point for H Piles. Alternatively, consideration may be given to pre-augering through the random fill prior to driving the piles into the native ground.

4. Suggested Text for NSSP on Groundwater Control

Water seepage due to perched water in the slope, random fill, surface runoff and precipitation should be expected. For temporary excavations for retaining wall construction at this site, groundwater control will likely be limited to diverting surface runoff and preventing precipitation from entering the excavations supplemented by sump pumping and use of perimeter ditches where required. Filtered sumps must be designed properly so that construction drainage water containing eroded soil and fines do not flow onto the existing roadways. Dewatering systems must be installed and made operational prior to excavating below the groundwater level. It is also important to minimize disturbance of the exposed sand and silt surfaces by limiting construction traffic. Vibratory rollers must not be used for preparation of a sand and silt subgrade.