FOUNDATION INVESTIGATION AND DESIGN REPORT
CULVERT REPLACEMENT NORTH OF DECEW ROAD
SITE NO. 34-292/C
HIGHWAY 406
THOROLD, ONTARIO
G.W.P. No. 2205-13-00

GEOCRES Number: 30M3-290

Report to

MMM Group Limited

Thurber Engineering Ltd.
2010 Winston Park Drive, Suite 103
Oakville, Ontario
L6H 5R7
Phone: (905) 829 8666
Fax: (905) 829 1166

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PART 1: FACTUAL INFORMATION

1. INTRODUCTION

This report presents the factual data obtained from a foundation investigation conducted by Thurber Engineering Ltd. (Thurber) for the proposed replacement of the existing culvert located on Highway 406, north of Decew Road, in Thorold, Ontario.

The purpose of this investigation was to explore the subsurface conditions at the culvert location and, based on the data obtained, to provide a borehole location plan, stratigraphic profile, records of boreholes, laboratory test results, and a written description of the subsurface conditions.

Thurber was retained by WSP/MMM Group Limited (MMM) to carry out this foundation investigation under the MTO Assignment Number 2014-E0030.

2. SITE DESCRIPTION

The culvert site is located on Highway 406, approximately 173 m north of Decew Road in Thorold, Ontario. This culvert allows the creek to flow from east to west, under Highway 406.

The existing structure is an open footing culvert. The culvert opening is 3.66 m wide and 1.52 m high. The existing culvert spans the entire highway platform width. The highway embankment in the vicinity of the culvert is approximately 2.5 m high, and there is 1.5 m of fill above the culvert. The grade of Highway 406 at the culvert location is at approximate Elevation 172.3 m. Based on an archived drawing, the culvert inlet (east) and outlet (west) levels are at approximate Elevations 169.84 and 169.77 m, respectively.

The land surrounding the existing culvert consist of agricultural lands, with trees along the east and west sides of Highway 406. The terrain is generally flat. Gibson Lake is located approximately 250 m south of the culvert. Gibson Lake serves as a storage reservoir for the Decew generating station.

Selected photographs of the culvert area are included in Appendix D for reference.

The site is situated within the physiographic region known as the Haldimand Clay Plain, which is characterized by glacio-lacustrine deposits laid down by the glacial Lake Warren during the Wisconsinian Age. These deposits consist of silts and clays and are generally underlain by a glacial till, which in turn overlies dolomitic limestone bedrock.

3. SITE INVESTIGATION AND FIELD TESTING

This borehole investigation and field testing program was carried out between September 6 to 8, 2016. The program consisted of drilling and sampling 6 boreholes (numbered 406-01 to 406-06) to depths ranging from 8.2 m to 12.8 m. All the boreholes were drilled near the existing culvert alignment. Boreholes 406-01 and 406-04 were drilled at the culvert outlet and inlet areas, respectively. Boreholes 406-02, 406-03, 406-05 and 406-06 were drilled through the highway embankments. Boreholes 406-05 and 406-06 were drilled to provide subsurface information for design of roadway protection.

Prior to the start of drilling, the borehole locations were marked/staked in the field and utility clearances were obtained. The co-ordinates and elevations of the as-drilled boreholes were subsequently provided by MMM Group Limited. The approximate borehole locations are shown on a Borehole Location and Soil Strata drawing included in Appendix C.

A truck-mounted B57 drill rig was used to drill and sample the boreholes through the highway embankments, and Geoprobe equipment was used to drill and sample the boreholes at the culvert inlet and outlet. Hollow stem augers were used to advance the boreholes until the target depth was reached. Soil samples were obtained at selected intervals using a 50 mm diameter split spoon sampler in conjunction with Standard Penetration Testing (SPT). Vane shear tests (VST) using an MTO ‘N’ size vane were conducted in the native silty clay to measure the in-situ undrained shear strength.

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, secured the recovered soil samples in labelled containers, and transported the samples to Thurber’s laboratory for further examination and testing.

Groundwater conditions in the open boreholes were observed throughout the drilling operations. The details of standpipe piezometer installations and borehole completion are summarized in Table 3.1.

The boreholes without piezometer installations were backfilled in accordance with O. Reg. 903. The piezometer installations will be decommissioned in accordance with O. Reg. 903.

Table 3.1 Borehole Completion and Standpipe Piezometer Installation Details

Borehole Number	Standpipe Piezometer Installations				Completion Details
	Tip Location (Depth/Elev.)	Screen Depth (m)	Screen Elevation (m)	Filter Stratum	
406-01	11.6 / 159.5	8.2 to 11.6	162.9 – 159.5	Silty Clay	Sand filter from 11.6 m to 8.2m, then bentonite holeplug from 8.6m to 7.7 m, holeplug and auger cuttings from 7.7 m to ground surface.
406-02	12.4 / 159.9	8.8 to 12.4	163.5 – 159.9	Silty Clay	Bentonite holeplug from 12.7 m to 12.4 m, sand from 12.4 m to 8.8 m, then holeplug from 8.8 m to ground surface.
406-03	-	None Installed			Borehole backfilled with bentonite holeplug and auger cuttings to 0.1 m, then asphalt to surface.
406-04	-	None Installed			Borehole backfilled with bentonite holeplug and auger cuttings to surface.
406-05	6.0 / 166.2	4.5 to 6.0	167.9 – 166.2	Silty Clay	Sand filter from 8.2 m to 4.3 m, then bentonite holeplug from 4.3m to 0.15 m, asphalt from 0.15 m to ground surface.
406-06	-	None Installed			Borehole backfilled with bentonite holeplug and auger cuttings to surface.

Results of field drilling and sampling are presented on the Record of Borehole sheets in Appendix A.

4. LABORATORY TESTING

All recovered soil samples were subjected to Visual Identification (VI) and to natural moisture content determination. Selected soil samples were subjected to grain size distribution analyses (sieve and hydrometer) and plasticity testing (Atterberg Limits). The results of this laboratory testing program are shown on the Record of Borehole sheets in Appendix A and on the figures in Appendix B.

5. DESCRIPTION OF SUBSURFACE CONDITIONS

5.1. General

Reference is made to the Record of Borehole sheets in Appendix A for details of the soil stratigraphy encountered in the boreholes. A stratigraphic profile for this culvert site is presented on the Borehole Locations and Soil Strata Drawings in Appendix C for illustrative purposes. An overall description of the stratigraphy is given in the following paragraphs; however, the factual data presented in the record of boreholes governs any interpretation of the site conditions.

In general, the subsurface conditions encountered in the boreholes consist of a pavement structure, or surficial topsoil, overlying silty clay embankment fill. An extensive deposit of native silty clay was contacted below the fill in all the boreholes. Groundwater levels are generally in the order of 1.8 to 2.2 m below original ground surface.

More detailed descriptions of the individual stratum are presented below.

5.2. Topsoil

A 200 mm thick layer of topsoil was encountered at ground surface in Boreholes 406-01, 406-04 and 406-06, drilled near the culvert inlet and outlet areas and on the Highway 406 median.

The topsoil thickness may vary between and beyond the borehole locations, and the limited data is not suitable for estimating topsoil quantities.

5.3. Pavement Structure

Boreholes 406-02, 406-03 and 406-05 were drilled from the paved platform of Highway 406. The pavement structure consisted of approximately 75 mm to 150 mm of asphalt over approximately 0.8 to 1.2 m of granular base material consisting of sand and gravel.

SPT 'N' values measured in the granular fill ranged from 12 to 25 blows per 0.3 m of penetration indicating a compact state. Measured moisture contents of the recovered granular fill samples varied from 4% to 6%.

5.4. Silty Clay Embankment Fill

Embankment fill was encountered in all the boreholes below the pavement structure and topsoil. This fill typically consists of brown silty clay with trace to some sand, trace gravel and occasional organics and rootlets. In Borehole 406-05, a 0.7 m thick layer of sand fill was contacted within the silty clay fill at 2.0 m depth (Elevation 170.2). The overall thickness of the silty clay fill ranged from 1.9 m to 2.8 m. The depth to the base of the silty clay fill ranged from 2.1 m to 2.9 m (Elevations 168.3 to 169.4).

SPT 'N' values measured in the cohesive fill ranged from 3 to 16 blows per 0.3 m of penetration indicating a soft to very stiff consistency, but typically soft to firm. Measured moisture contents of the recovered silty clay fill samples ranged between 8% and 25%, with most values ranging from 15% to 24%.

Three laboratory grain size distribution analyses were performed on samples of the silty clay fill and one grain size distribution analysis was performed on a sample of sand fill. The results of these tests are presented on the corresponding Record of Borehole sheets in Appendix A and the grain size distribution curves are plotted in Figures B1 and B2 of Appendix B. Atterberg Limits tests conducted on selected samples of the silty clay fill are presented on the Record of Borehole sheets included in Appendix A and on Figure B5 of Appendix B. The laboratory test results are summarized in the following table.

Soil Particles	Silty Clay Fill	Sand Fill
Gravel	0	1
Sand	0 to 13	81
Silt	48 to 63	11
Clay	33 to 48	7

Soil Property	Percentage (%)
Liquid Limit	36 to 43
Plasticity Index	18 to 23

The results of the limits testing indicate that the silty clay fill is of medium plasticity with a group symbol of CI.

5.5. Silty Clay

Native brown to grey silty clay was encountered below the silty clay fill in the six boreholes drilled on site at depths ranging from 2.1 m to 4.0 m. The silty clay contained trace sand. All the boreholes were terminated within the silty clay at depths ranging from 8.2 m to 12.8 m (Elevations 159.4 m to 164.0 m).

Within the upper 2 m of the silty clay deposit, SPT ‘N’ values measured in the native silty clay ranged from 4 to 9 blows per 0.3 m of penetration indicating a firm to stiff consistency. Below this upper zone, the ‘N’ values ranged between 0 and 5 blows per 0.3 m penetration. Vane shear tests (VST) conducted in the silty clay in Boreholes 406-02 and 406-03 measured in-situ undrained shear strength in the range of 70 kPa to 90 kPa. Based on the VST data, plasticity indices and measured moisture contents of the silty clay, the consistency of the silty clay typically ranges from soft to stiff. Measured moisture contents of the recovered silty clay samples varied from 21% and 45%.

Eight laboratory grain size distribution analyses were performed on samples of the silty clay. The results of these tests are presented on the corresponding Record of Borehole sheets in Appendix A and the grain size distribution curves are plotted in Figures B3 and B4 of Appendix B. Atterberg Limits tests conducted on selected samples of the silty clay are presented on the Record of Borehole sheets included in Appendix A and included in Figure B6 and B7 of Appendix B. The laboratory test results are summarized in the following table.

Soil Particles	%
Gravel	0
Sand	0 to 10
Silt	39 to 65
Clay	27 to 55
Soil Property	**%**
Liquid Limit	23 to 38
Plasticity Index	8 to 19

The results of the Atterberg Limits tests indicate that the silty clay is typically low to medium plastic with dual group symbols (CL-CI).

5.6. Groundwater Conditions

Water was not observed in the boreholes upon completion of drilling. Standpipe piezometers were installed in Boreholes 406-01, 406-02 and 406-05 to permit longer term monitoring. Water levels measured in the three installed standpipes are presented below.

Table 5.1 – Groundwater Measurements

Borehole	Date of Reading	Water Level Depth (m)	Water Level Elevation (m)
406-01	September 30, 2016 December 8, 2016	1.8 0.9	169.3 170.2
406-02	September 30, 2016 December 8, 2016	2.2 1.9	170.1 170.4
406-05	September 30, 2016 December 8, 2016	Not read 2.2	Not read 170.0

The readings above indicate that the measured piezometric levels coincide with the creek water level which was estimated to be in the order of Elevations 170.2 to 170.4 m on December 8, 2016.

The groundwater level should be assumed to reflect the local creek water level. The groundwater levels above are short-term readings and seasonal fluctuations of the groundwater levels are to be expected. In particular, the groundwater levels may be at a higher elevation after periods of significant or prolonged precipitation.

6. MISCELLANEOUS

Thurber staked and/or marked the borehole locations in the field and obtained utility clearances prior to drilling. MMM Group Limited provided the northing and easting coordinates and ground surface elevations.

Landshark Drilling of Brantford, Ontario supplied and operated a truck-mounted drill rig B57 and a Geoprobe equipment to carry out the drilling, sampling and in-situ testing operations.

The drilling and sampling operations in the field were supervised on a full time basis by Mr. Abdul Nasri of Thurber. Geotechnical laboratory testing was carried out by Thurber in its MTO approved Toronto laboratory.

Overall project management was provided by Dr. Sydney Pang, P.Eng. Interpretation of the field data and preparation of this report was completed by Ms. R. Palomeque Reyna, P. Eng. and Dr. Pang. The report was reviewed by Dr. P.K. Chatterji, P.Eng., a Designated Principal Contact for MTO Foundations Projects.

THURBER ENGINEERING LTD.

LICENSED PROFESSIONAL ENGINEER
R. Palomeque Reyna
100083209
Dec/12/16
PROVINCE OF ONTARIO

Rocío Palomeque Reyna, P.Eng.
Geotechnical Engineer

LICENSED PROFESSIONAL ENGINEER
S. PANG
Dec 12/16
PROVINCE OF ONTARIO

Sydney Pang, P.Eng.,
Associate, Senior Foundations Engineer

LICENSED PROFESSIONAL ENGINEER
P. K. CHATTERJI
Dec 12/16
PROVINCE OF ONTARIO

P. K. Chatterji, P.Eng.,
Review Principal, Designated MTO Contact

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PART 2: ENGINEERING DISCUSSION AND RECOMMENDATIONS

7. GENERAL

This report presents interpretation of the geotechnical data in the factual report and provides foundation recommendations for the design of the replacement of the existing culvert located on Highway 406, north of Decew Road in Thorold, Ontario.

Based on a General Arrangement (GA) drawing dated November 2016 provided by MMM, the existing structure is a open footing culvert. The existing culvert opening is 3.66 m wide by 1.52 m high. The highway embankment at this location is up to 2.5 m in height. The invert level of the culvert opening is at approximate Elevation 169.6 m.

The discussions and recommendations presented in this report are based on information provided by MMM Group Limited and on the factual data obtained during course of this investigation.

8. CULVERT FOUNDATIONS

8.1 General

The GA drawing indicates that current project requirements involve replacement of the existing open footing culvert with a concrete box culvert along the same alignment. The invert and alignment of the replacement culvert and the finished road grade level will remain largely the same as for the existing culvert. Physical exterior dimensions of the proposed culvert are presented in the table below.

Table 8-1. Physical Data of Proposed Replacement Culvert

Borehole Numbers	Approx. Invert Elevation (m)		Approx. Length (m)	Approx. Width (m)	Approx. Height (m)
	Inlet	Outlet			
406-01 and 406-04 near inlet/outlet	169.5	169.5	68.9	4.0	2.3
406-02, 406-03, 406-05 and 406-06 through highway embankment adjacent to culvert					

8.2 Foundation Alternatives

This section presents discussions on available types of replacement culverts and foundation alternatives, and provides recommendations on feasible and/or preferred foundation option. Several common culvert and foundation types are listed below and a comparison of these alternatives, based on their respective advantages and disadvantages, is included in Appendix E.

<u>Concrete, Open Footing Culvert</u>

Concrete, open footing, culvert is feasible, however, from a foundation engineering perspective, the compressible silty clay subgrade at shallow depths will provide low geotechnical resistances and has potential for post construction settlement. Foundation recommendations for an open footing culvert has not been developed in this report.

<u>Circular Pipes (Concrete, Steel, HDPE)</u>

From a foundation engineering standpoint, concrete, steel and HDPE pipes are technically feasible alternatives provided that other design issues including flow capacity, hydraulic properties and durability can be satisfied. Multiple pipes may be required to provide adequate hydraulic capacity. It is understood that this option is not considered at this site and therefore foundation recommendations for pipe culverts are not further developed.

<u>Concrete Box (Closed) Culvert</u>

Given the subsurface conditions and the anticipated construction sequencing, precast concrete box culvert is the preferred culvert replacement option from a foundation engineering standpoint. Precast sections, rather than cast-in-place construction, can be installed rapidly with less potential for disturbance of the founding soils during installation.

This report focuses on providing foundation recommendations for the design and construction of a concrete box culvert.

8.3 Foundation Design

It is understood that the invert levels of the replacement culvert are approximately the same as those of the existing culvert. Foundation design aspects for the replacement culvert include subgrade conditions, settlement of founding soils, lateral earth pressures, erosion control, protection system design and groundwater control, staged excavation, and stability of widening detour embankment where required.

8.3.1 Concrete Box Culvert

Since the replacement culvert will be constructed on the same alignment as the existing culvert, it is anticipated that the subgrade soil within the culvert footprint will not be subjected to any significant additional loading.

Based on the design information to date, the combined thickness of the concrete base slab and the underlying granular pad is approximately 0.55 m. The proposed founding level of the culvert box is therefore at about Elevation 169 m. From the borehole results, the subgrade soils at this elevation typically consist of stiff to firm native silty clay. The presence firm silty clay fill in localized areas, such as that depicted in the vicinity of Borehole 406-04, is possible.

In order to provide a uniform foundation subgrade, a 300 mm thick layer of bedding material conforming to OPSS PROV 1010 Granular A or Granular B Type II requirements should be provided under the base of the box culvert, similar to that shown on OPSD 803.010. The bedding material must be placed on the prepared subgrade as soon as practicable following its inspection and approval. The subgrade preparation, placement and compaction of the bedding material must be carried out in the dry. The surface prepared to support the box units should have a 75 mm minimum thickness top levelling course consisting of uncompacted Granular A as per OPSS 422. Construction equipment should not be allowed to travel on the bedding or the prepared subgrade, which must be protected from disturbance during construction.

The following geotechnical capacities may be used for design of the proposed box culvert founded at or below Elevation 169 m on a stiff to firm silty clay subgrade:

- Factored Geotechnical Resistance at ULS of 200 kPa
- Geotechnical Resistance at SLS (less than 25 mm settlement) of 125 kPa.

A consequence factor of 1 was utilized in this design adopting the typical consequence level. The geotechnical resistance factor of 0.5 for bearing, and 0.8 for settlement, both adopted for typical degree of understanding, were used to obtain the above values, as per CHBDC 2014, Sec. 6.9.

The ULS resistance and settlement are dependent on the culvert size, configuration and applied loads; the geotechnical resistances should therefore be reviewed if the culvert width or founding/invert elevation differs significantly from that given above.

The geotechnical resistances are for vertical, concentric loads. Where eccentric or inclined loads are applied, the resistance used in design must be reduced in accordance with the CHBDC 2014, Clause 6.10.3 and Clause 6.10.4.

Resistance to lateral forces / sliding resistance between pre-cast concrete and the underlying Granular A or B Type II should be calculated assuming an ultimate coefficient of friction of 0.45.

It is recommended that the culvert be designed to resist external loadings including frost forces, lateral earth pressures, hydrostatic pressure, weight of the embankment fill, traffic loadings and surcharge due to construction equipment.

8.3.2 Settlements

It is understood that there is no grade raise at this site. The existing open footing culvert is to be replaced with a concrete box culvert along the same alignment. Taking into consideration the anticipated construction sequencing for this site, it is anticipated that rebound of the subgrade after removal of the existing culvert and the surrounding fill will be negligible.

It is estimated that the marginal increase in weight of the new culvert over the existing culvert would result in negligible additional settlement.

8.3.3 Subgrade Preparation

After the excavation reaches the design founding elevation, any remaining fill, topsoil, creekbed deposits, disturbed soils and any deleterious materials within the culvert replacement footprint must be sub-excavated to undisturbed native firm to stiff silty clay at or below the desired founding elevations. The exposed surface must be inspected to confirm that the subgrade is suitable and uniformly competent. Any soft areas should be sub-excavated and replaced with well compacted granular fill consisting of OPSS.PROV 1010 Granular A or B Type II material compacted as per OPSS.PROV 501.

This work must be carried out in accordance with OPSS 902 and construction must be carried out in the dry. Any area of deeper excavation required for removal of the existing culvert footings should be restored with concrete fill and/or approved compacted materials as per OPSS 902.

8.4 Construction Considerations

Staged open cutting will be employed to construct the replacement culvert at this site. The main foundation/geotechnical considerations are as follows:

- Traffic and creek flow will be maintained at all times during construction
- Unwatering methods such as temporary diversion of the creek and surface water using sandbags and/or sheetpile cofferdams may be required.
- Cofferdams may be required to be installed at the inlet and outlet areas as part of the creek flow and surface water diversions
- Roadway protection will be required during all stages of construction
- Excavation and removal of the existing culvert, installation of the new culvert and backfilling will be carried out within the protection systems
- Sump pumping will be required at all times. All works are to be carried out in the dry.

Protection systems (temporary shoring) such as the use of interlocking steel sheetpiles will be required. Foundation recommendations for design of such a system are provided in Section 14 of this report.

9. CULVERT BACKFILL AND LATERAL EARTH PRESSURES

It is recommended that backfill to the culvert consists of free-draining, non-frost susceptible granular materials such as Granular A or B Type II conforming to the requirements of OPSS.PROV 1010. Reference should be made to the backfill arrangements stipulated in OPSD 803.01 as appropriate.

All fills must be placed in regular lifts and be compacted in accordance with OPSS.PROV 501. The backfill must be placed and compacted in simultaneous lifts on both sides of the culvert, and the difference of the top of backfill elevation on both sides of the culvert should be kept within 500 mm of each other at all times. Heavy compaction equipment must not be used adjacent to the culvert.

For a rigid structure such as concrete box culvert, it is recommended that at-rest horizontal earth pressures be used for design.

Earth pressures acting on the culvert walls may be assumed to impose a triangular distribution. For a fully drained backfill, the pressures should be computed in accordance with the CHBDC 2014 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 below)
γ = bulk unit weight of retained soil (see table below)
h = depth below top of fill where pressure is computed (m)
q = value of any surcharge (kPa)

Earth pressure coefficients for backfill are dependent on the material used as backfill. Recommended unfactored values are shown in the following Table 9.1. Active pressures should be used for any unrestrained wall.

Table 9.1
Earth Pressure Coefficients (K)

<table>
<tr><th rowspan="3">Wall Condition</th><th colspan="6">Earth Pressure Coefficient (K)</th></tr>
<tr><th colspan="2">OPSS Granular A or OPSS Granular B Type II
$\phi = 35°$; $\gamma = 22.8\ kN/m^3$</th><th colspan="2">OPSS Granular B Type I (modified)
$\phi = 32°$; $\gamma = 21.2\ kN/m^3$</th><th colspan="2">Embankment Fill
$\phi = 30°$; $\gamma = 20.0\ kN/m^3$</th></tr>
<tr><th>Horizontal Surface Behind Wall</th><th>Sloping Surface Behind Wall (2H:1V)</th><th>Horizontal Surface Behind Wall</th><th>Sloping Surface Behind Wall (2H:1V)</th><th>Horizontal Surface Behind Wall</th><th>Sloping Surface Behind Wall (2H:1V)</th></tr>
<tr><td>Active (Unrestrained Wall)</td><td>0.27</td><td>0.40</td><td>0.31</td><td>0.48</td><td>0.33</td><td>0.54</td></tr>
<tr><td>At rest (Restrained Wall)</td><td>0.43</td><td>0.62</td><td>0.47</td><td>0.70</td><td>0.50</td><td>0.76</td></tr>
<tr><td>Passive (Movement Towards Soil Mass)</td><td>3.7</td><td>-</td><td>3.3</td><td>-</td><td>3.0</td><td>-</td></tr>
</table>

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 at a depth of 1.7 m for Granular A or Granular B Type II. Compaction equipment to be used adjacent to the culvert walls should be restricted in accordance with OPSS.PROV 501.

10. EMBANKMENT DESIGN AND CONSTRUCTION

The existing highway embankment is up to 2.5 m in height at the culvert. It is understood that that there is no planned grade raise at this site.

Embankment reconstruction after culvert replacement should be carried out in accordance with OPSS 206. The embankment material should consist of imported Granular A or B Type II material.

Provided that the granular material is placed as recommended, it is anticipated that the existing slope inclination of 4H : 1V, should remain stable. Where applicable, benching of the existing earth slope surface should be carried out as per OPSD 208.010 in order to enhance the keying in of the new fill.

In general, surface vegetation, peat, topsoil, organic deposits, disturbed material or otherwise loose/soft soils should be stripped from the areas around the culvert inlet and outlet, and within the embankment footprints. Inspection and approval of the foundation surfaces by qualified geotechnical personnel is recommended.

11. EROSION CONTROL

Erosion protection should be provided at the culvert inlet and/or outlet areas. Design of the erosion protection measures must consider hydrologic and hydraulic factors and should be carried out by specialists experienced in this field.

Typically, rock protection should be provided over all surfaces with which creek water is likely to be in contact. Treatment at the outlets should be in accordance with OPSD 810.010. A vegetation cover should be established on all other exposed earth surfaces to protect against surficial erosion in general accordance with OPSS 804.

It is recommended that a clay seal or a concrete cut-off wall be used to minimize the potential for erosion near the inlet area. The clay seal should extend a minimum of 0.3 m above the high water level and laterally for the width of the granular material, and have a minimum thickness of 0.5 m. The material requirements should be in accordance with OPSS 1205. A geosynthetic clay liner may be used as a clay seal.

12. EXCAVATION AND GROUNDWATER CONTROL

12.1 General

All excavations must be carried out in accordance with the Occupational Health and Safety Act (OHSA). For the purposes of the OHSA, the embankment fill and native silty clays at this site are classified as Type 3 soils. Surficial alluvial deposits that are anticipated in the inlet and outlet areas are classified as Type 4 soils.

12.2 Foundations

Excavation and backfilling for culvert construction must be carried out in accordance with OPSS 902.

Excavated granular fill and silty clay fill should not be reused as backfill and should be disposed of off-site.

12.3 Excavations

Excavations for culvert replacement will typically be carried out through the existing embankment fill and extended into the native silty clay deposits. The work will be carried out in association with a roadway protection system that is understood to be installed in the median area parallel to the highway centreline. In the transverse direction (perpendicular to the highway centreline), the GA drawing shows open cutting at an inclination of 1H : 1V. This option is considered feasible based on existing borehole information.

12.4 Groundwater Control

Groundwater perched within the embankment fill will seep into the excavations during culvert replacement. Surface runoff will also tend to accumulate in these excavations. The groundwater level is expected to be largely governed by the water level in the creek. As discussed in the previous section 8.4, a combination of the use of cofferdams at the inlet and outlet, creek water diversion, protection systems such as sheetpiled enclosures and pumping from filtered sumps may be required to maintain dry excavations during the course of staged construction.

The design of an effective dewatering system that may be required is the responsibility of the Contractor and the Contract Documents must alert him to this responsibility and the need to engage a dewatering specialist. Dewatering must remain operational and effective until the culvert is installed and backfilled. Suggesting wording for an NSSP in this regard is included in Appendix F.

13. SEISMIC CONSIDERATIONS

In accordance with the CHBDC 2014, the selection of the seismic site classification is based on the soil conditions encountered in the upper 30 m of the stratigraphy. The stratigraphy of the site includes a low to medium plastic, soft to firm, silty clay layer of greater than 3 m in thickness. This corresponds to a Seismic Site Class D in accordance with Table 4.1, Clause 4.4.3.2 of the CHBDC. The peak ground acceleration, PGA, for a 2% in 50-year probability of exceedance at this site is 0.204g as per the National Building Code of Canada (NBCC).

In accordance with Clause 4.6.5 of the CHBDC 2014, retaining structures should be designed using active (KAE) and passive (KPE) 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 Earthquake Loading

Condition	Earth Pressure Coefficient (K)		
	OPSS Granular A or Granular B Type II $\phi = 35°, \gamma = 22.8$ kN/m^3	OPSS Granular B Type I (modified) $\phi = 32°, \gamma = 21.2$ kN/m^3	Existing Fill $\phi = 30°, \gamma = 20$ kN/m^3
Active (K_{AE})*	0.38	0.42	0.46
Passive (K_{PE})	3.3	2.9	2.7
At Rest (K_{OE})**	0.76	0.8	0.83

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

** After Woods

The site is underlain by silty clay and liquefaction is not considered to be a concern at this site.

14. ROADWAY PROTECTION DESIGN

Roadway protection will be required during various stages of construction.

Any protection system must be designed by licensed Professional Engineers experienced in such designs. OPSS.PROV 539 “Construction Specification for Protection Systems” should be included in the contract documents. It is recommended that Performance Level 2 as per Clause 539.04.02.01 (maximum horizontal displacement of 25 mm) be specified for this culvert replacement site.

One option that is considered to be suitable for use at this site is steel interlocking sheetpiles which are also anticipated to provide an effective groundwater cutoff. It is anticipated that the sheetpiles will need to be socketted into the upper firm to stiff portion of the native silty clay to develop the required toe resistance. It is anticipated that the shoring system may be stiffened by corner and cross bracings, where applicable.

An interlocking sheetpiled wall may be designed using the parameters given below:

γ	=	20 kN/m^3
γ_w	=	10 kN/m^3
K_a	=	0.33 (road embankment fill)
	=	0.36 (silty clay)
K_p	=	2.8 (silty clay)

Full hydrostatic pressure should be considered assuming a water level at least equal to the design creek water level.

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.

The designer of the roadway protection system must check whether the penetration depth is sufficiently deep to provide base fixity.

All roadway protection systems must be designed by a Professional Engineer experienced in such designs.

15. CONSTRUCTION CONCERNS

During construction, the Contract Administrator should employ experienced geotechnical staff to observe construction activities related to foundation construction and to inspect and approve the culvert subgrade.

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

- Impact of excavation on the existing pavement surface.

Daily visual inspection of the pavement surface must be carried out in the vicinity of the culvert replacement. If cracks form in the pavement or settlement is observed to occur, these matters must immediately be brought to the attention of the C.A. for determining as to whether remedial action is required

- A section of culvert close to the centreline of Highway 406 will be a cast in place box section to provide an opening for existing sewer outlets. Care must be exercised during sub-excavation, removal of the existing culvert foundations, and construction of the new culvert. The existing sewer pipes must be protected from any damage during construction of the new culvert.
- Removal of peat, organics, soft soils and alluvial deposits near creek channels particularly in the inlet and outlet areas
- Confirmation that the culvert backfills and approach fills are adequately placed and compacted to specifications.
- Even though not encountered during the field investigation, buried obstructions may be encountered during excavation in the existing fill and may interfere with installation of the temporary roadway protection system. Suggested wording for an NSSP on obstructions is included in Appendix F.

It is recommended that provision(s) be included in the contract requiring the QVE to confirm that the above issues are adequately addressed. Should there be any doubts about issues such as depth of sub-excavation, these provisions should require the QVE to alert the CA.

15 CLOSURE

Preparation of this foundation design report was carried out by Ms. R. Palomeque Reyna, P. Eng. and Dr. Sydney Pang, P.Eng. The report was reviewed by Dr. P.K. Chatterji, P.Eng.

THURBER ENGINEERING LTD.

Rocío Palomeque Reyna, P.Eng.
Geotechnical Engineer

Sydney Pang, P.Eng.
Associate, Senior Foundations Engineer

P.K. Chatterji, P.Eng.
Review Principal, Designated MTO Contact

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			

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No 406-01

METRIC

GWP# 2258-15-00 | LOCATION Decew Road N 4 774 385.0 E 326 180.3 | ORIGINATED BY AN

HWY 406 | BOREHOLE TYPE Geoprobe | COMPILED BY AN

DATUM Geodetic | DATE 2016.09.08 - 2106.09.08 | CHECKED BY RPR

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
171.1	GROUND SURFACE					
0.0	**TOPSOIL:** (200mm)				171	
0.2	Silty **CLAY**, trace sand, trace gravel, occasional roots Stiff to Very Stiff Brown Moist (FILL)	1	SS	10		
		2	SS	15	170	
		3	SS	16		0 0 52 48
169.0 / 2.1	Silty **CLAY**, trace sand Stiff to Firm Light Brown Moist				169	
		4	SS	9		
		5	SS	4	168	0 0 54 46
167.0 / 4.1	Soft to Very Soft Grey Wet				167	
		6	SS	1	166	
		7	SS	2	165	
		8	SS	1	164, 163	
		9	SS	1	162	

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

Continued Next Page

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

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

ONTMT4S MTO-11336.GPJ 2015TEMPLATE(MTO).GDT 12/12/16

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No 406-01

METRIC

GWP# 2258-15-00 LOCATION Decew Road N 4 774 385.0 E 326 180.3 ORIGINATED BY AN

HWY 406 BOREHOLE TYPE Geoprobe COMPILED BY AN

DATUM Geodetic DATE 2016.09.08 - 2106.09.08 CHECKED BY RPR

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	WATER CONTENT (%)	UNIT WEIGHT kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Continued From Previous Page									
	Silty **CLAY**, trace sand Soft Grey Wet						161			
			10	SS	2		160			
159.5 11.6	END OF BOREHOLE AT 11.6m UPON REFUSAL TO AUGER ADVANCE. BOREHOLE DRY UPON COMPLETION OF DRILLING. Piezometer installation consists of 25mm diameter Schedule 40 PVC pipe with a 3.0m slotted screen.									

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

WATER LEVEL READINGS

DATE	DEPTH(m)	ELEV.(m)
2016.09.30	1.8	169.3
2016.12.08	0.9	170.2

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

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No 406-02

METRIC

GWP# 2258-15-00 LOCATION Decew Road N 4 774 382.5 E 326 202.1 ORIGINATED BY AN

HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY AN

DATUM Geodetic DATE 2016.09.06 - 2016.09.06 CHECKED BY RPR

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%) / SHEAR STRENGTH	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
172.3	GROUND SURFACE						
0.0	**ASPHALT:** (75mm)						
0.2	**SAND** and **GRAVEL**, trace silt Compact Brown Moist (FILL)	1	SS	21	172		
		2	SS	12			
170.9 1.4	Silty **CLAY**, trace sand, trace gravel, occasional organics Firm Brown Moist (FILL)	3	SS	6	171		
		4	SS	7	170		
169.4 2.9	Silty **CLAY**, trace sand Firm Brown Moist	5	SS	7	169		
		6	SS	4	168		0 0 58 42
		7	SS	6	167		
166.7 5.6	Stiff to Very Soft Grey Wet	8	SS	2	166	Field vane: 3.5	
	Trace gravel	9	SS	2	165, 164		
		10	SS	0	163		Split spoon sampler wet

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 406-02

METRIC

GWP# 2258-15-00 | LOCATION Decew Road N 4 774 382.5 E 326 202.1 | ORIGINATED BY AN

HWY 406 | BOREHOLE TYPE Hollow Stem Augers | COMPILED BY AN

DATUM Geodetic | DATE 2016.09.06 - 2016.09.06 | CHECKED BY RPR

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	SHEAR STRENGTH kPa	WATER CONTENT (%)	UNIT WEIGHT kN/m³	GR	SA	SI	CL
	Continued From Previous Page											
	Silty **CLAY**, trace to some sand Very Soft to Soft Grey Wet				162							
		11	SS	1								
					161	3.5 (field vane)						
					160							
159.6 / 12.7		12	SS	4					0	10	63	27

END OF BOREHOLE AT 12.7m UPON REFUSAL TO SPLIT SPOON SAMPLER ADVANCE.
BOREHOLE DRY UPON COMPLETION OF DRILLING.
Piezometer installation consists of 19mm diameter Schedule 40 PVC pipe with a 3.0m slotted screen.

WATER LEVEL READINGS

DATE	DEPTH(m)	ELEV.(m)
2016.09.30	2.2	170.1
2016.12.08	1.9	170.4

Legend: 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; REMARKS & GRAIN SIZE DISTRIBUTION (%)

+ 3, × 3 : Numbers refer to Sensitivity

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

RECORD OF BOREHOLE No 406-03

METRIC

GWP# 2258-15-00	LOCATION Decew Road N 4 774 378.5 E 326 222.7		ORIGINATED BY AN
HWY 406	BOREHOLE TYPE Hollow Stem Augers		COMPILED BY AN
DATUM Geodetic	DATE 2016.09.07 - 2016.09.07		CHECKED BY RPR

ELEV / DEPTH	SOIL PROFILE DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	FIELD VANE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
172.3	GROUND SURFACE							
0.0	**ASPHALT:** (150mm)							
0.2	**SAND** and **GRAVEL**, trace silt Compact Brown Moist (FILL)	1	SS	20	172	○		
		2	SS	24		○		
170.9 / 1.4	Silty **CLAY**, trace sand, trace gravel, occasional organics Soft to Firm Grey Brown Wet (FILL)	3	SS	3	171	○		Split spoon sampler wet
		4	SS	7	170	○		
169.4 / 2.9	Silty **CLAY**, trace sand Stiff to Firm Grey Moist	5	SS	9	169	○		
		6	SS	5	168	├○┤		0 0 65 35
166.7 / 5.6	Soft to Very Soft Wet	7	SS	1	167 / 166	○	+ 4.5	
		8	SS	3	165 / 164	├○┤		0 4 41 55
	Firm	9	SS	5	163	○		

Column headings: SOIL PROFILE; 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 Next Page

+³, ×³: Numbers refer to Sensitivity

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

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 406-03

METRIC

GWP# 2258-15-00 | LOCATION Decew Road N 4 774 378.5 E 326 222.7 | ORIGINATED BY AN

HWY 406 | BOREHOLE TYPE Hollow Stem Augers | COMPILED BY AN

DATUM Geodetic | DATE 2016.09.07 - 2016.09.07 | CHECKED BY RPR

Continued From Previous Page

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)
	Silty **CLAY**, trace sand Firm to Stiff Grey Wet				162	
		10	SS	4		○ (~25)
					161	
					160	
		11	SS	13		○ (~22)
159.5 12.8	END OF BOREHOLE AT 12.8m. BOREHOLE DRY UPON COMPLETION OF DRILLING. BOREHOLE BACKFILLED WITH BENTONITE HOLEPLUG TO 0.1m, THEN ASPHALT PATCH TO SURFACE.					

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

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

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THURBER

RECORD OF BOREHOLE No 406-04

METRIC

GWP# 2258-15-00 LOCATION Decew Road N 4 774 385.0 E 326 240.9 ORIGINATED BY AN

HWY 406 BOREHOLE TYPE Geoprobe COMPILED BY AN

DATUM Geodetic DATE 2016.09.08 - 2016.09.08 CHECKED BY RPR

ELEV / DEPTH	SOIL PROFILE – DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
171.3	GROUND SURFACE						
0.0	**TOPSOIL:** (200mm)						
0.2	Silty **CLAY**, trace sand, trace gravel, occasional organics, occasional rootlets Firm Brown Moist (FILL)	1	SS	4	171		
		2	SS	4		wP–w–wL	0 4 63 33
					170		
		3	SS	7			
					169		
		4	SS	4			
168.3 3.0	Silty **CLAY**, trace sand Stiff to Firm Brown Moist						
		5	SS	9	168		
					167		
		6	SS	5			
					166		
165.7 5.6	Firm to Soft Grey						
		7	SS	2	165	wP–w–wL	0 6 39 55
					164		
		8	SS	4			
					163		
					162		
		9	SS	2			

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 wP, NATURAL MOISTURE CONTENT w, LIQUID LIMIT wL; WATER CONTENT (%) 20 40 60

UNIT WEIGHT γ kN/m3

GROUND WATER CONDITIONS

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 406-04

METRIC

GWP# 2258-15-00 | LOCATION Decew Road N 4 774 385.0 E 326 240.9 | ORIGINATED BY AN

HWY 406 | BOREHOLE TYPE Geoprobe | COMPILED BY AN

DATUM Geodetic | DATE 2016.09.08 - 2016.09.08 | CHECKED BY RPR

Continued From Previous Page

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Silty **CLAY**, trace sand, trace gravel Soft Grey Moist to Wet	(hatched)					161				
			10	SS	3				~35		
159.4							160				
11.9	END OF BOREHOLE AT 11.9m UPON REFUSAL TO AUGER ADVANCE. BOREHOLE DRY UPON COMPLETION OF DRILLING. BOREHOLE BACKFILLED WITH BENTONITE HOLEPLUG AND CUTTINGS TO SURFACE.										

Legend: DCPT scale 20 40 60 80 100; Shear strength: ○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE; Plastic limit w_P, Natural moisture content w, Liquid limit w_L; Water content 20 40 60.

+³, ×³: Numbers refer to Sensitivity

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

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 406-05

METRIC

GWP# 2258-15-00 LOCATION Decew Road N 4 774 387.4 E 326 212.6 ORIGINATED BY AN

HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY AN

DATUM Geodetic DATE 2016.09.07 - 2016.09.07 CHECKED BY RPR

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
172.2	GROUND SURFACE				
0.0	**ASPHALT:** (75mm)				
0.1	**SAND** and **GRAVEL**, trace silt, Compact, Brown, Moist (FILL)	1	SS	25	
171.3 / 0.9	Silty **CLAY**, trace sand, occasional organics, Firm to Stiff, Brown, Moist (FILL)	2	SS	5	
		3	SS	9	
170.2 / 2.0	**SAND**, trace gravel, some silt, trace clay, Loose, Reddish Brown, Moist (FILL)	4	SS	9	1 81 11 7
169.3 / 2.9	Silty **CLAY**, trace sand, Stiff to Firm, Brown, Wet	5	SS	15	
		6	SS	8	Split spoon sampler wet
		7	SS	5	
164.0		8	SS	4	0 6 43 51
8.2	END OF BOREHOLE AT 8.2m.				

END OF BOREHOLE AT 8.2m.
BOREHOLE DRY UPON COMPLETION OF DRILLING.
Piezometer installation consists of 19mm diameter Schedule 40 PVC pipe with a 1.52m slotted screen.

WATER LEVEL READINGS

DATE	DEPTH(m)	ELEV.(m)
2016.12.08	2.2	170.0

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; GROUND WATER CONDITIONS; ELEVATION SCALE (172, 171, 170, 169, 168, 167, 166, 165, 164); DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100); SHEAR STRENGTH kPa (○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × 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

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No 406-06

METRIC

GWP# 2258-15-00 | LOCATION Decew Road N 4 774 373.8 E 326 212.3 | ORIGINATED BY AN

HWY 406 | BOREHOLE TYPE Hollow Stem Augers | COMPILED BY AN

DATUM Geodetic | DATE 2016.09.06 - 2016.09.06 | CHECKED BY RPR

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	GR	SA	SI	CL
171.5	GROUND SURFACE								
0.0	**TOPSOIL:** (200mm)								
0.2	Silty **CLAY**, some sand, occasional organics, occasional rootlets; Firm to Stiff; Brown; Moist; (FILL)	1	SS	5					
		2	SS	8					
		3	SS	10		0	13	48	39
168.8		4	SS	10					
2.7	Silty **CLAY**, trace sand; Firm to Soft; Brown; Moist	5	SS	5		0	0	63	37
		6	SS	4					
	Grey; Wet	7	SS	2					
163.3		8	SS	3					
8.2	END OF BOREHOLE AT 8.2m. BOREHOLE DRY UPON COMPLETION OF DRILLING. BOREHOLE BACKFILLED WITH BENTONITE HOLEPLUG AND CUTTINGS TO SURFACE.								

Column headings: SOIL PROFILE (ELEV DEPTH, DESCRIPTION, STRAT PLOT); SAMPLES (NUMBER, TYPE, "N" VALUES); GROUND WATER CONDITIONS; ELEVATION SCALE (171, 170, 169, 168, 167, 166, 165, 164); DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × 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

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

Appendix B

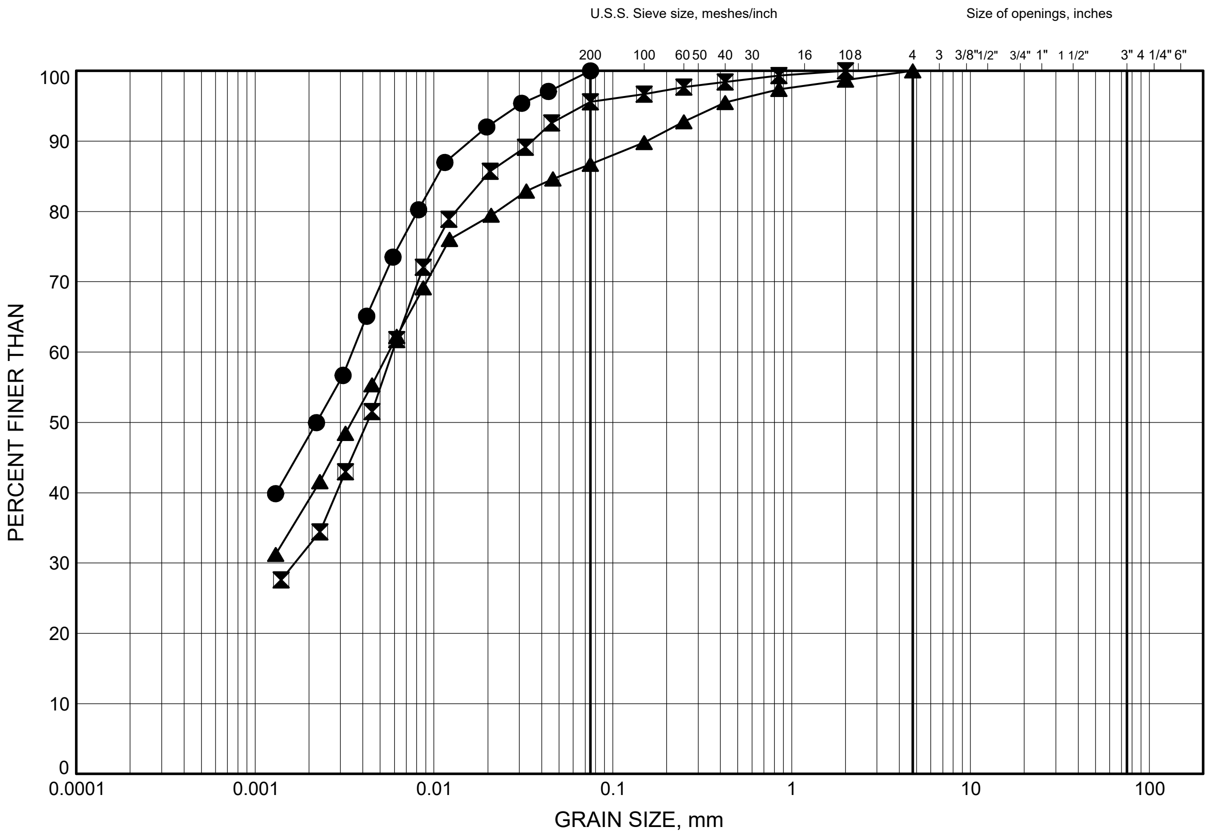
Laboratory Test Results

Decew Road

GRAIN SIZE DISTRIBUTION

FIGURE B1

Silty CLAY FILL



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	406-01	1.83	169.27
⧗	406-04	1.07	170.23
▲	406-06	1.83	169.67

GRAIN SIZE DISTRIBUTION - THURBER MTO-11336.GPJ 12/12/16

Date December 2016

GWP# 2258-15-00

THURBER

Prep'd AN

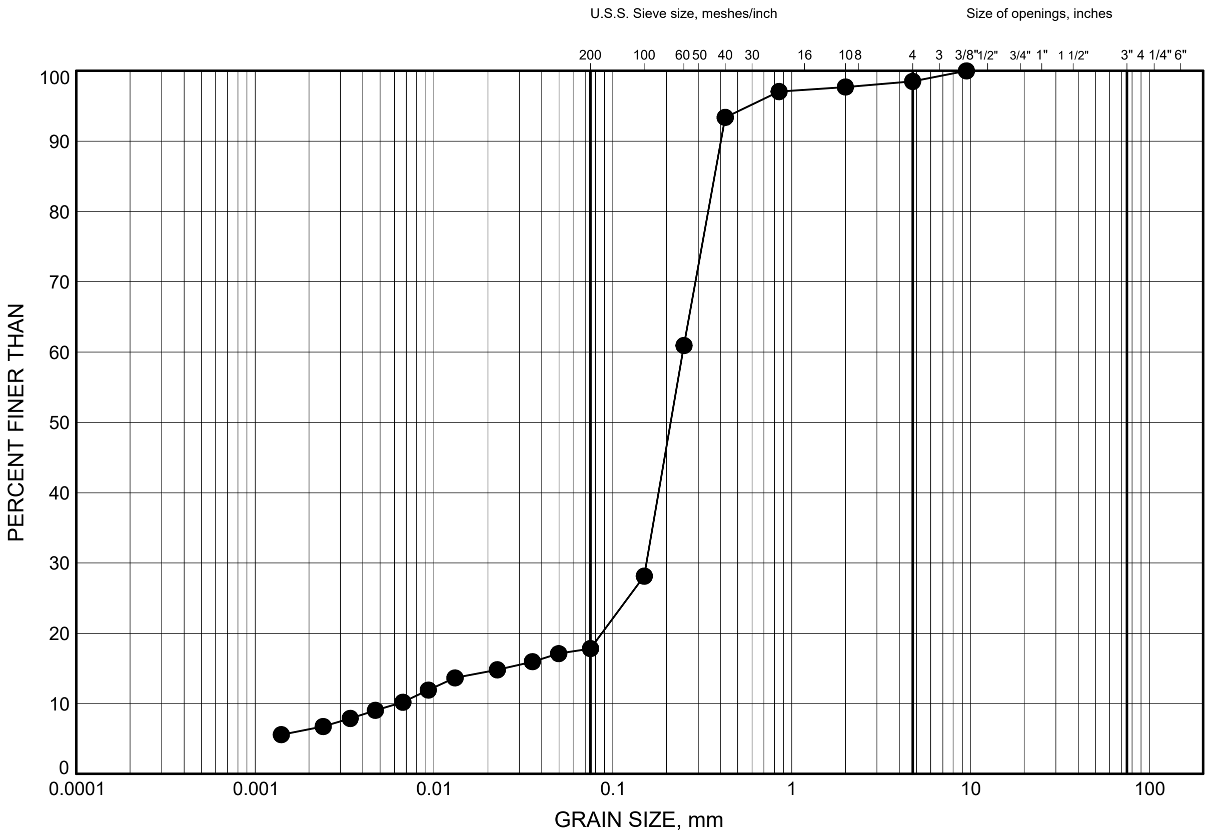
Chkd. RPR

Decew Road

GRAIN SIZE DISTRIBUTION

FIGURE B2

SAND FILL



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	406-05	2.44	169.76

GRAIN SIZE DISTRIBUTION - THURBER MTO-11336.GPJ 12/12/16

Date December 2016

GWP# 2258-15-00

THURBER

Prep'd AN

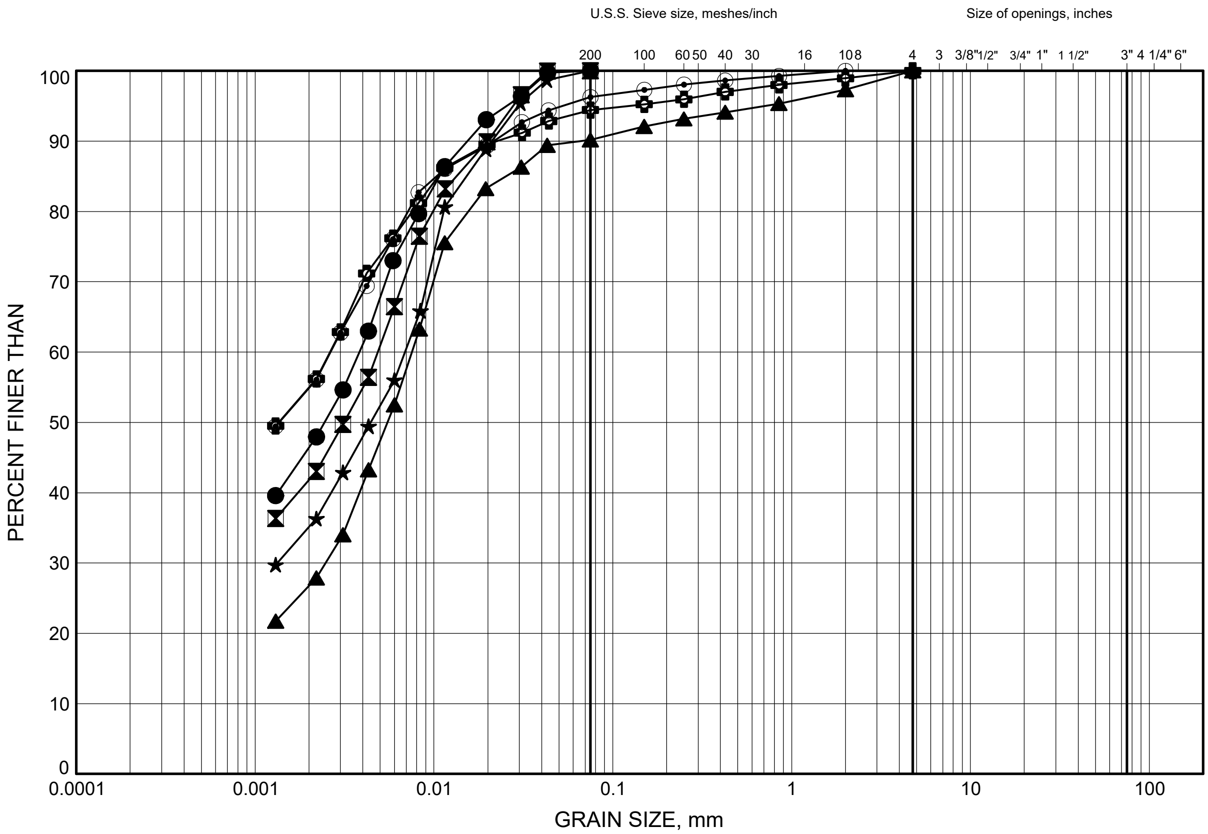
Chkd. RPR

Decew Road

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)
●	406-01	3.35	167.75
⧗	406-02	4.11	168.19
▲	406-02	12.50	159.80
★	406-03	4.88	167.42
⊙	406-03	7.92	164.38
✿	406-04	6.40	164.90

GRAIN SIZE DISTRIBUTION - THURBER MTO-11336.GPJ 12/12/16

Date December 2016

GWP# 2258-15-00

THURBER

Prep'd AN

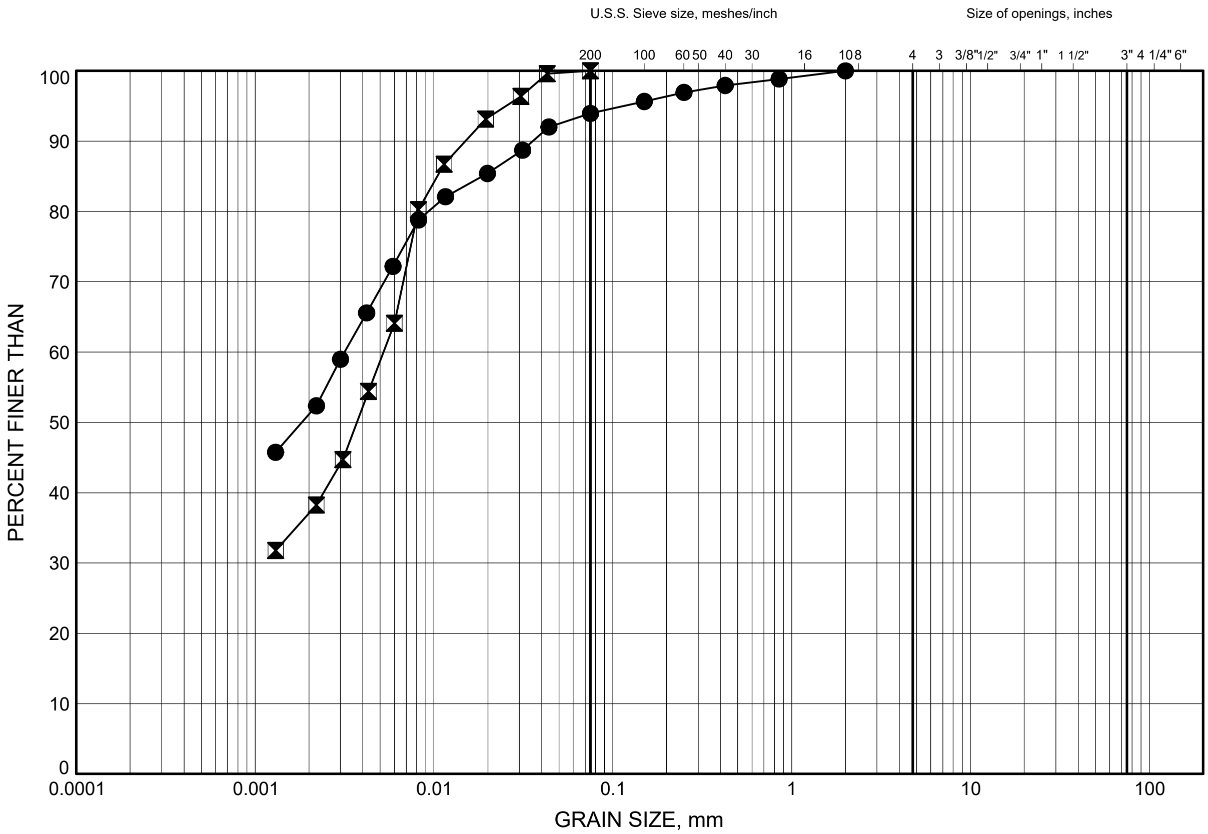
Chkd. RPR

Decew Road

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)
●	406-05	7.92	164.28
⧗	406-06	3.35	168.15

Date December 2016

GWP# 2258-15-00

THURBER

Prep'd AN

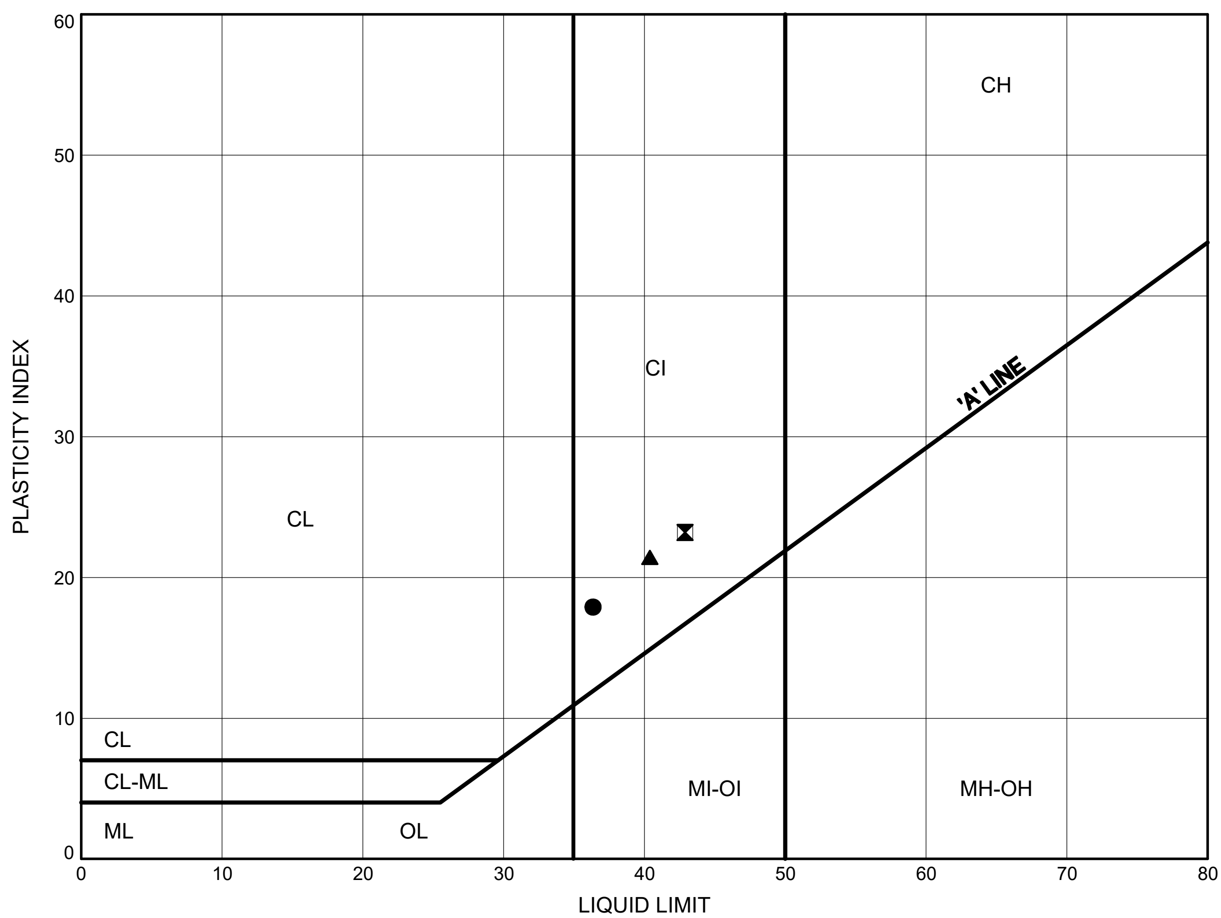
Chkd. RPR

Decew Road

ATTERBERG LIMITS TEST RESULTS

FIGURE B5

Silty CLAY FILL



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	406-01	1.83	169.27
⧗	406-04	1.07	170.23
▲	406-06	1.83	169.67

THURBALT MTO-11336.GPJ 12/12/16

Date December 2016

GWP# 2258-15-00

THURBER

Prep'd AN

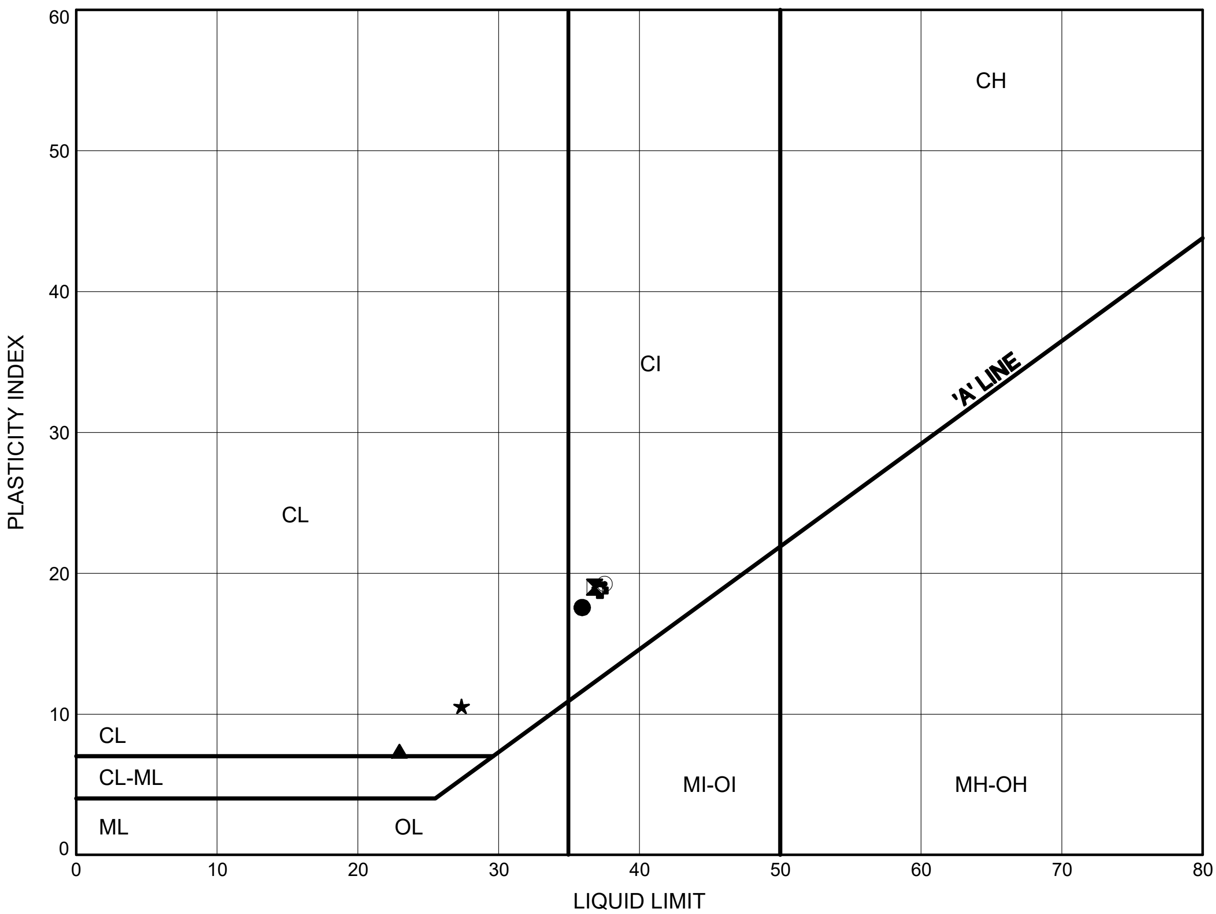
Chkd. RPR

Decew Road

ATTERBERG LIMITS TEST RESULTS

FIGURE B6

Silty CLAY



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	406-01	3.35	167.75
⧗	406-02	4.11	168.19
▲	406-02	12.50	159.80
★	406-03	4.88	167.42
⊙	406-03	7.92	164.38
✿	406-04	6.40	164.90

Date December 2016

GWP# 2258-15-00

THURBER

Prep'd AN

Chkd. RPR

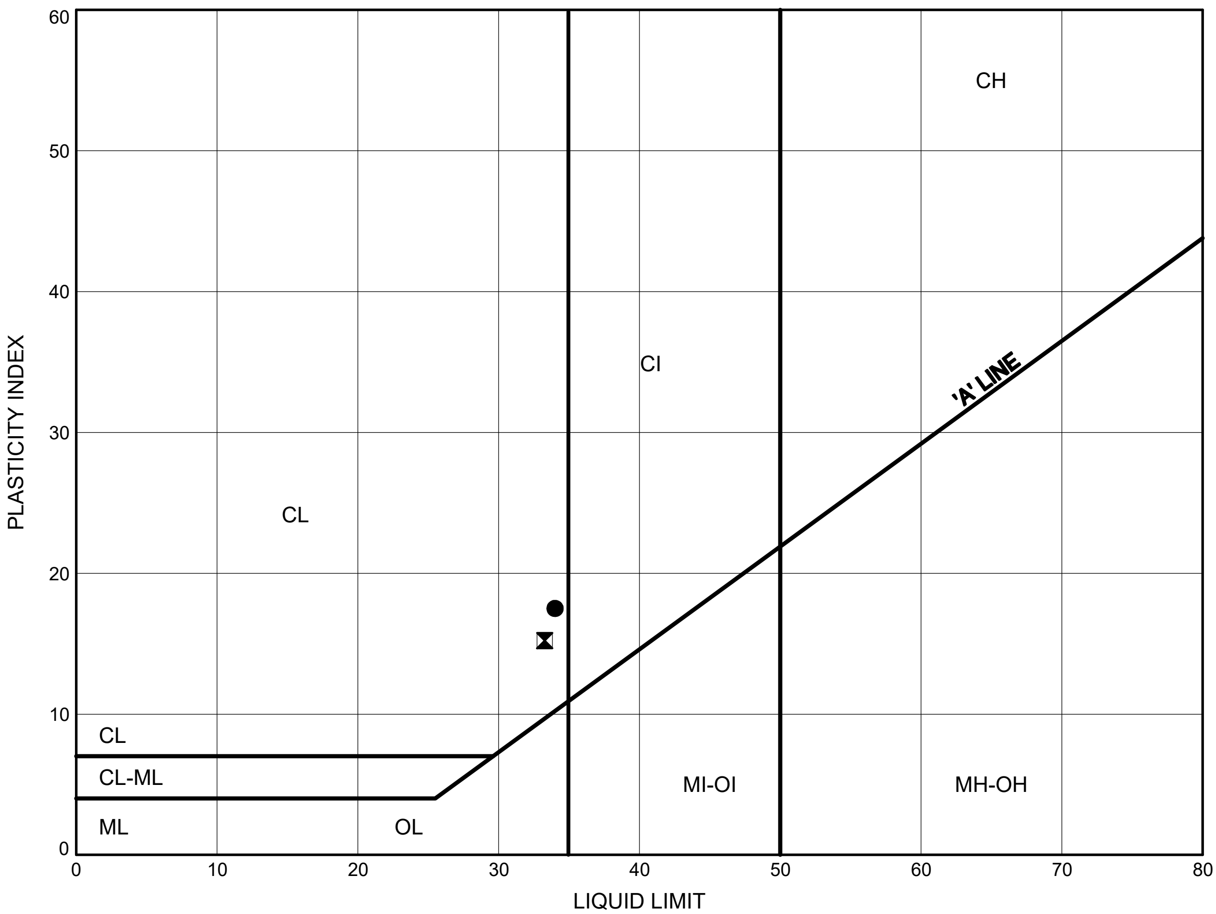
THURBALT MTO-11336.GPJ 12/12/16

Decew Road

ATTERBERG LIMITS TEST RESULTS

FIGURE B7

Silty CLAY



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	406-05	7.92	164.28
⧗	406-06	3.35	168.15

THURBALT MTO-11336.GPJ 12/12/16

Date December 2016

GWP# 2258-15-00

THURBER

Prep'd AN

Chkd. RPR

Appendix C

Borehole Locations and Soil Strata Drawings

METRIC

DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN

CONT No

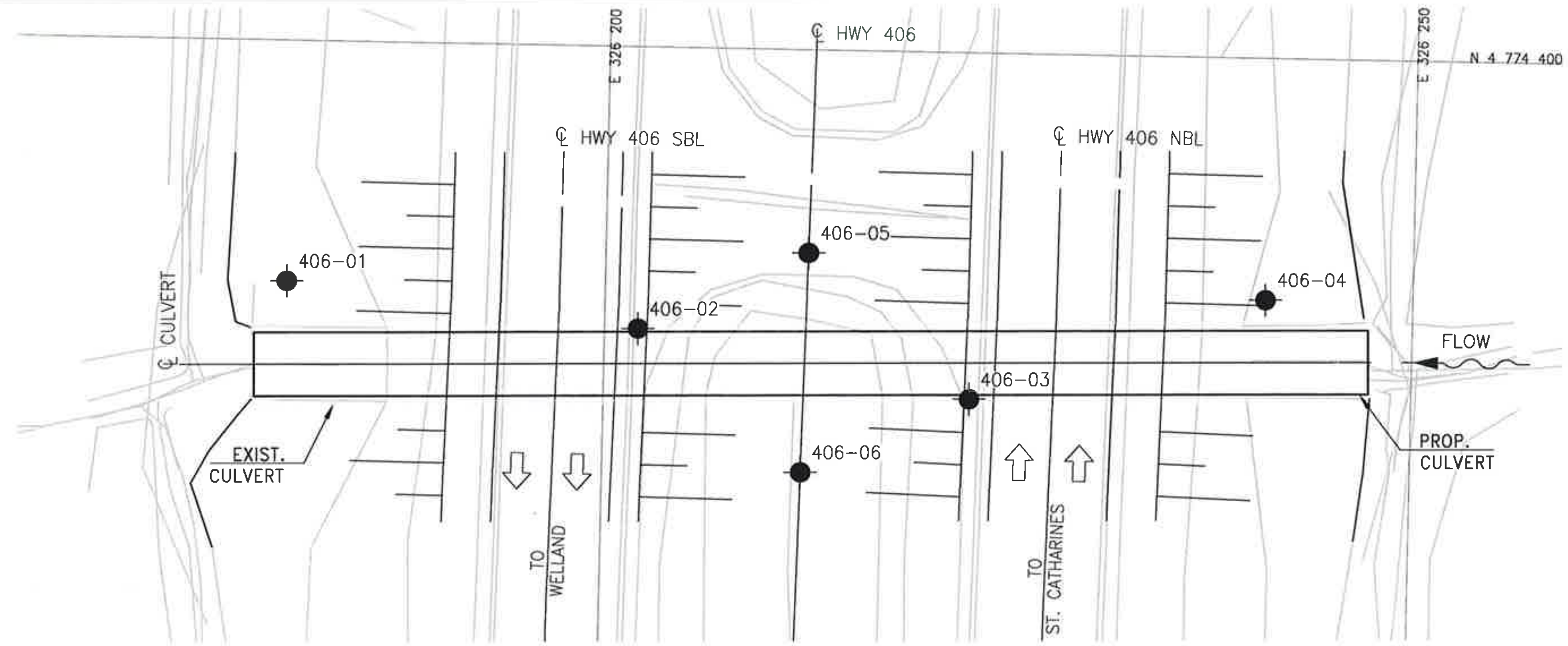
WP No 2258–15–00

HIGHWAY 406
CULVERT NORTH OF DECEW RD.
REPLACEMENT
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET

MMM GROUP

THURBER ENGINEERING LTD.



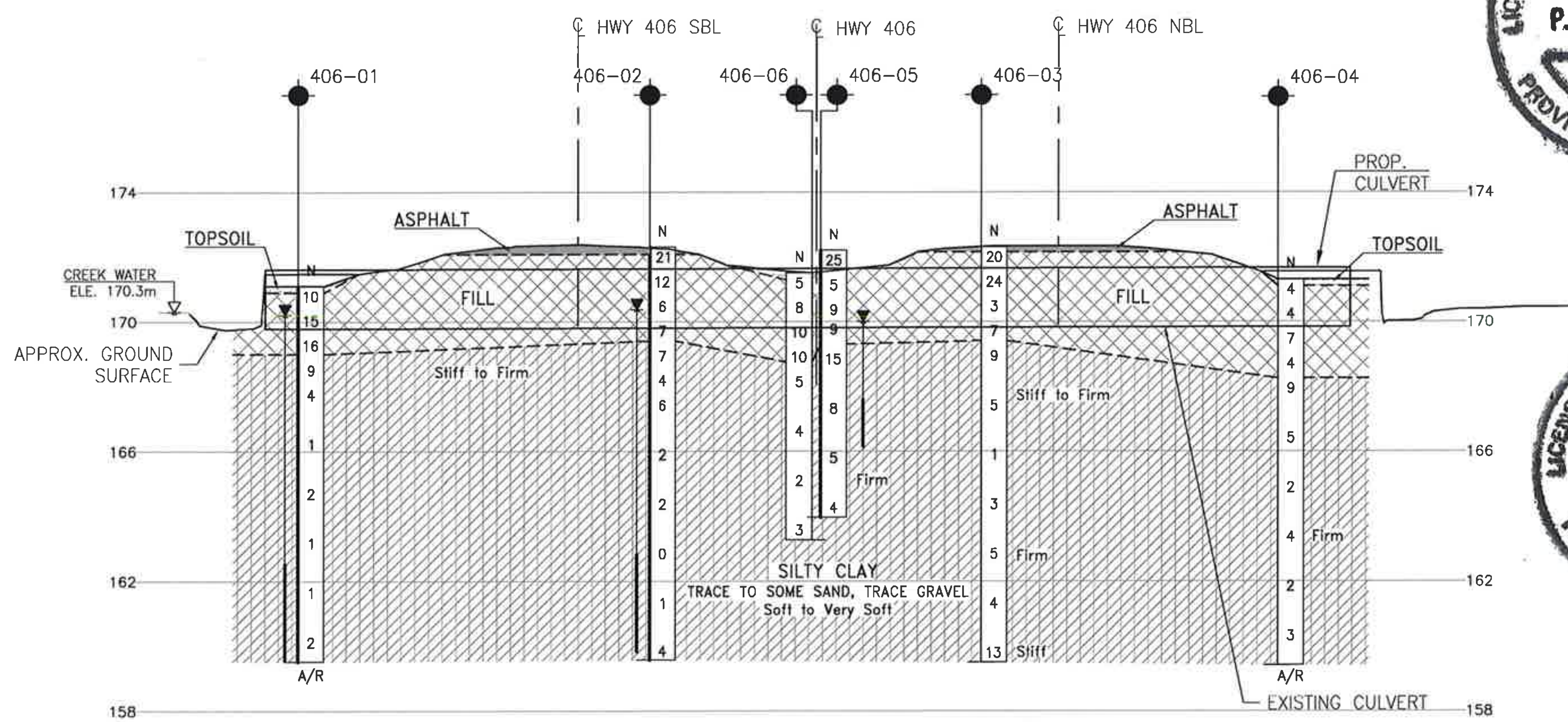
PLAN

SCALE 1:400

KEYPLAN

P. N. CHATTERJI
LICENSED PROFESSIONAL ENGINEER
PROVINCE OF ONTARIO
Dec 12/16

S. PANG
LICENSED PROFESSIONAL ENGINEER
PROVINCE OF ONTARIO
Dec 12/16



SECTION ALONG ℄ CULVERT

H 1:400

V 1:200

LEGEND

Symbol	Description
●	Borehole
⊕	Borehole and Cone
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
406-01	171.1	4 774 385.0	326 180.3
406-02	172.3	4 774 382.5	326 202.1
406-03	172.3	4 774 378.5	326 222.7
406-04	171.3	4 774 385.0	326 240.9
406-05	172.2	4 774 387.4	326 212.6
406-06	171.5	4 774 373.8	326 212.3

-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. 30M3-290

REVISIONS	DATE	BY	DESCRIPTION

DESIGN RPR	CHK SKP	CODE	LOAD	DATE DEC 2016
DRAWN AN	CHK RPR	SITE	STRUCT	DWG 2

FILENAME: H:\Drafting\11000\11336\TED-11336-PLPR-0C.dwg
PLOTDATE: 12/12/2016 2:07 PM

Appendix D

Selected Photograph of Culvert Site

Photo 1.- Culvert, looking north

Photo 2.- Culvert, looking south

Photo 3.- Culvert, east side

Photo 4.- Culvert, west side

Appendix E

Foundation Alternatives Comparisons

COMPARISON OF ALTERNATIVE CULVERT TYPES

Concrete Box (Closed) Culvert	Concrete Open Footing Culvert	Circular Pipe (concrete, steel, HDPE) Culvert
Advantages: i. Relatively rapid installation and less disturbance to subgrade soils if precast units are used. ii. Less requirement for soil geotechnical resistances as loading is spread over a larger width. ***Disadvantages:*** i. Require sub-excavation for granular pad construction in the dry	***Advantages:*** i. Relatively rapid installation if precast units are used. ii. May have less environmental issues such as those involving spawning fish species. ***Disadvantages:*** i. Requires higher soil geotechnical resistances to support strip footings. ii. May require deeper sub-excavation for strip footing construction.	***Advantages:*** i. May be installed using trenchless methods. ii. Steel and HDPE pipes may be more cost effective than concrete box and open footing culverts. ***Disadvantages:*** i. Steel and HDPE may not be as durable as concrete. ii. Possible hydraulic and/or hydrologic issues.
RECOMMENDED	**NOT RECOMMENDED**	**FEASIBLE**

Appendix F

List of OPSS and Suggested Wordings for NSSP

1. List of OPSS Documents Relevant this Project

- OPSS 206
- OPSS 422
- OPSS 501
- OPSS 804
- OPSS 902
- OPSS PROV 1010
- OPSD 803.01
- OPSD 810.010
- OPSD 208.010

2. Suggested Wording for NSSP on Dewatering

Effective dewatering shall be designed and provided by the Contractor during structure excavation, bedding placement and backfilling to allow the work to proceed in the dry. Excavation below the creek and groundwater level will lead to subgrade softening. The dewatering system must be effective to maintain the water level below the final subgrade level throughout construction. The dewatering system must remain operational and effective until the culvert is installed and backfilled.

3. Suggested Wording for NSSP on Obstructions

Excavations and installation of cofferdams and roadway protection systems could encounter obstructions embedded in the fill and native soils. Such obstructions may impede excavation progress and/or sheet pile installation. The Contractor shall be prepared to remove, drill through and/or penetrate these obstructions to achieve the design depths.