FOUNDATION INVESTIGATION AND DESIGN REPORT
PAGWACHUAN RIVER TRIBUTARY CULVERT REPLACEMENT
HIGHWAY 11
DISTRICT OF THUNDER BAY, ONTARIO

G.W.P. 6134-04-00, SITE No. 48E-69/C

Geocres Number: 42F-31

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 proposed location of the replacement culvert carrying Highway 11 over the Pagwachuan River tributary located approximately 70 km east of Longlac, in the District of Thunder Bay, Ontario.

The purpose of this investigation was to explore the subsurface conditions at the site and, based on the data obtained, to provide a borehole location plan, 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 in the course of the investigation.

Thurber carried out the investigation as a sub-consultant to MMM Group Limited (MMM), under the Ministry of Transportation Ontario (MTO) Agreement Number 6010-E-0011.

2 SITE DESCRIPTION

The existing Pagwachuan River Tributary culvert is located approximately 70 km (by highway) east of Longlac, Ontario and about 12 km west of the intersection of Highway 11 and South Pagwachuan Road. Pagwachuan River Tributary is a tributary of the main Pagwachuan River, which runs in a meandering west to east direction, south of Highway 11. At the existing Highway 11 crossing, the tributary flows in a general north to south direction before meeting the main Pagwachuan River.

The culvert under the existing highway embankment consists of a 25.5 m long timber culvert with twin 2.1 by 1.75 m openings and the highway embankment is approximately 2.1 m high. Preliminary drawings provided by MMM indicate a water level of Elev. 222.4 m in the Pagwachuan River Tributary in April 2011.

The surrounding lands are densely treed with grass and shrubs in close proximity to the highway. Photographs in Appendix C show the existing Pagwachuan River Tributary culvert and the general nature of the site.

The site lies within the physiographic region known as the Quetico Subprovince of the Superior Province of the Canadian Shield. Based on Ontario Geological Survey (OGS) Map s365, titled "Algoma-Cochrane Surficial Geology", dated 1962, the site is located in an area consisting of lacustrine deposits of varved clay and silt, fine sand, and clayey till ground moraine. The bedrock in the region is early Precambrian and based on OGS Map 2543, titled "Bedrock Geology of Ontario, East-Central Sheet", dated 1991, the bedrock consists of metasedimentary bedrock (paragneiss and migmatites).

3 SITE INVESTIGATION AND FIELD TESTING

The site investigation and field testing for this project was carried out between June 7 and 10, 2014. The investigation comprised drilling and sampling four boreholes identified as Boreholes PCT-01 to PCT-04 along the proposed replacement culvert alignment. Boreholes PCT-01 and PCT-04 were drilled near the proposed inlet and outlet respectively, and Boreholes PCT-02 and PCT-03 were drilled on the west and east sides of the culvert alignment through the existing highway embankment.

The approximate borehole locations are shown on the attached Borehole Locations and Soil Strata Drawing in Appendix F.

The borehole locations were marked in the field and utility clearances were obtained prior to drilling.

The boreholes were advanced to depths of 12.3 to 14.5 m (Elev. 210.3 to 209.5 m), including recovery of 2.5 to 3.5 m of bedrock core. The drilling was carried out using a track mounted CME 55 drill rig with NW casing and wash boring techniques. Soil samples were obtained at selected intervals in the boreholes using a split spoon sampler in conjunction with Standard Penetration Testing (SPT). In situ vane shear testing was conducted to further assess the undrained shear strength of the cohesive deposits. Sampling of the underlying rock was conducted using NQ size diamond coring equipment.

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. All rock cores were logged, and the Total Core Recovery (TCR), Rock Quality Designation (RQD) and the Fracture Indices (FI) were determined.

Standpipe piezometers were installed in two boreholes to measure groundwater levels. The piezometers were subsequently decommissioned in general accordance with MOE Regulation 903 following completion of the final water level reading. The piezometer installation and borehole completion details are summarized in Table 3.1.

Table 3.1 – Borehole Completion and Piezometer Installation Details

Borehole	Piezometer Tip Depth/ Elev. (m)	Completion and Installation Details
PCT-01	8.5 / 214.0	19 mm diameter piezometer installed with filter sand from 8.5 m to 6.7 m, bentonite holeplug from 6.7 to 5.2 m, then cuttings and bentonite holeplug to surface.
PCT-02	None installed	Backfilled with bentonite holeplug to 0.6m, concrete to 0.1 m, then asphalt cold patch to surface.
PCT-03	None installed	Backfilled with bentonite holeplug to 0.6m, concrete to 0.1 m, then asphalt cold patch to surface.
PCT-04	8.8 / 213.2	19 mm diameter piezometer installed with filter sand from 8.8 m to 3.7 m, then bentonite holeplug from 3.7 m to surface.

4 LABORATORY TESTING

The recovered soil samples were subjected to Visual Identification (VI) and to natural moisture content determination. Selected samples were also subjected to gradation analysis (hydrometer and sieve) and Atterberg Limits testing, where appropriate. The results of these tests are summarized on the Record of Borehole sheets included in Appendix A and are presented on the figures included in Appendix B.

Point load tests were carried out on selected samples of intact bedrock to assist in evaluation of the compressive strength of the bedrock. The results of point load tests on the rock core samples are presented on the Record of Borehole sheets in Appendix A.

5 DESCRIPTION OF SUBSURFACE CONDITIONS

Reference is made to the Record of Borehole sheets included in Appendix A. Details of the encountered soil stratigraphy are presented in these sheets and on the "Borehole Locations and Soil Strata" drawing included in Appendix F. An overall description of the stratigraphy is given in the following paragraphs. However, the factual data presented in the Record of Borehole sheets governs any interpretation of the site conditions.

In general, the subsurface stratigraphy encountered at the culvert site consisted of existing embankment fill overlying thin layers of sand and silty clay, underlain by deposits of silt to sandy silt and silty clay. The silty clay was underlain by discontinuous units of silty clay till and sand and gravel overlying bedrock. Peaty topsoil was encountered at the ground surface in the off-road boreholes, and a thin layer of buried peat was identified below the embankment fill. More detailed descriptions of the individual strata are presented below.

5.1 Pavement Structure

A pavement structure comprising 100 to 125 mm of asphalt overlying 400 to 900 mm of sand and gravel was encountered at the highway surface in Boreholes PCT-02 and PCT-03.

SPT N-values of 54 and 67 blows per 0.3 m penetration were recorded in the sand and gravel fill, indicating a very dense relative density. Moisture contents of the sand and gravel fill ranged from 3 to 11%.

One sample of the sand and gravel fill was selected for laboratory grain size analysis testing. The results of the test are summarized below and are presented on the corresponding Record of Borehole sheet included in Appendix A. The grain size distribution curve for the sample is plotted on Figure B1 of Appendix B.

Gravel %	36
Sand %	57
Silt and Clay %	7

5.2 Sand Fill

Existing embankment fill consisting of sand with some gravel and trace silt was encountered beneath the sand and gravel fill in Boreholes PCT-02 and PCT-03. The thickness of the sand fill was 1.8 and 1.6 m with a lower boundary encountered at depths of 2.3 and 2.6 m (Elev. 221.7 and 221.4 m).

SPT N-values recorded in the fill ranged from 8 to 24 blows per 0.3 m penetration, indicating a loose to compact relative density. Moisture contents of the sand fill ranged from 10 to 16%.

One sample of the sand fill was selected for laboratory grain size analysis testing. The results of the test are summarized below and are presented on the corresponding Record of Borehole sheet included in Appendix A. The grain size distribution curve for the sample is plotted on Figure B2 of Appendix B.

Gravel %	15
Sand %	71
Silt and Clay %	14

5.3 Topsoil and Peat

A 200 to 300 mm thick layer of peaty topsoil was encountered at the ground surface in Boreholes PCT-01 and PCT-04 drilled adjacent to the roadway embankment. Moisture contents of 24% and 40% were measured in this layer.

A 200 mm thick layer of peat was encountered beneath the sand fill in Borehole PCT-02. The lower boundary of the peat layer was encountered at a depth of 2.5 m (Elev. 221.5 m). A moisture content of 391% was measured in this material. In Borehole PCT-03, a seam of organic material was noted at the base of the sand fill at 2.6 m depth (Elev. 221.4).

5.4 Silty Clay

A relatively thin layer of silty clay with trace sand and gravel was encountered below the topsoil and a thin sand layer in Borehole PCT-01, the peat layer in Borehole PCT-02, the sand fill in Borehole PCT-03 and the topsoil in Borehole PCT-04. The clay was described as brown to brownish grey, and contained trace organics. The thickness of this layer ranged from 0.4 to 1.2 m with a lower boundary encountered at depths of 0.8 to 3.3 m (Elev. 220.7 to 221.2 m).

SPT N-values of 0 to 5 blows for 0.3 m penetration were recorded in tests carried out within or partially within the clay, indicating a very soft to firm consistency. Locally in Borehole PCT-03, an N-value of 22 blows for 0.3 m penetration was recorded, indicating a stiff consistency. The moisture content of the deposit ranged from 18 to 46%.

5.5 Sand to Silty Sand

A layer consisting of silty sand with some gravel to sand with some silt and gravel (to gravelly) was encountered beneath the silty clay layer in Boreholes PCT-01 to PCT-03. The thickness of the sand layer ranged from 0.3 to 0.8 m with a lower boundary encountered at depths of 2.0 to 4.1 m (Elev. 220.5 to 219.9 m). A 0.3 m thick sand layer with organics was also encountered below the topsoil in Borehole PCT-01.

SPT N-values recorded partially within the sand layer ranged from 8 to 13 blows for 0.3 m penetration, indicating a loose to compact condition. Measured moisture contents in the silty sand to sand layer ranged from 7 to 19%.

Three samples of the silty sand to sand layer were selected for laboratory grain size analysis testing. The results of the tests are summarized below and are presented on the corresponding Record of Borehole sheets included in Appendix A. The grain size distribution curves for the samples are plotted on Figure B3 of Appendix B.

Gravel %	13 to 26
Sand %	54 to 63
Silt and Clay %	17 to 25

5.6 Silt to Sandy Silt

A layer varying in composition from silt, some clay, trace sand to sandy silt, trace clay, trace gravel was encountered beneath the silty clay in Borehole PCT-04 and the silty sand to sand layer in the remaining boreholes. The silt/sandy silt was described as light brown to dark greyish brown, and contained clay seams in Boreholes PCT-01 and PCT-02, as well a wood pieces in the upper 0.6 m of this layer in Borehole PCT-04. The thickness of this layer ranged from 1.5 to 3.1 m with a lower boundary encountered at depths of 3.0 to 6.5 m (Elev. 219.0 to 217.5 m).

SPT N-values recorded in the silt to sandy silt typically ranged from 6 to 10 blows per 0.3 m penetration, indicating a loose relative density. Locally, an N-value of 1 blow for 0.3 m (very loose) was recorded in the upper 0.6 m of this layer in Borehole PTC-04, and an N-value of 19 blows for 0.3 m (compact) was obtained in Borehole PCT-02. Measured moisture contents typically ranged from 15 to 25%, with one value of 65% from Borehole PCT-04.

Three samples of the silt to sandy silt layer were selected for laboratory grain size analysis testing. The results of the tests are summarized below and are presented on the corresponding Record of Borehole sheets included in Appendix A. The grain size distribution curves for the samples are plotted on Figure B4 of Appendix B.

Gravel %	0 to 2
Sand %	6 to 38
Silt %	50 to 78
Clay %	8 to 16

5.7 Lower Silty Clay

A lower layer of silty clay was encountered beneath the silt to sandy silt layer in all boreholes. The silty clay was described as brown, dark brown or greyish brown, typically contained silt seams, and in some zones contained trace sand and gravel. The thickness of this layer varied between 3.7 and 5.1 m with a lower boundary encountered at depths of 7.8 to 11.2 m (Elev. 214.7 to 212.8 m).

SPT N-values of 0 to 16 blows per 0.3 m penetration was recorded in the silty clay. In situ shear vane testing indicated undrained shear strengths varying from 31 to 53 kPa. Based on this data, the consistency of the silty clay is generally firm to stiff. The measured moisture contents in this layer varied between 20 and 57%.

The results of grain size distribution analyses conducted on five samples of the silty clay are presented on the Record of Borehole sheets in Appendix A and on Figure B5 in Appendix B. The results of Atterberg Limits testing conducted on the samples are presented on the Record of Borehole sheets and plotted on Figure B7 of Appendix B. The results are are summarized below.

Gravel %	0 to 2
Sand %	0 to 9
Silt %	34 to 59
Clay %	37 to 66
Liquid Limit %	26 to 46
Plastic Limit %	14 to 20

The results indicate that the silty clay displays low to medium plasticity with a group symbol of CL to CI.

5.8 Silty Clay Till

A discontinuous deposit of silty clay till was encountered beneath the silty clay in Borehole PCT-01. This deposit was 1.4 m thick and overlies bedrock at 9.2 m depth (Elev. 213.3). Till-like layers were also noted within the lower part of the silty clay stratum in Boreholes PCT-03 and PCT-04.

An SPT N-value of 11 blows per 0.3 m penetration was recorded in the silty clay till, indicating a stiff consistency. Moisture contents of 9% and 13% were measured in this layer.

Glacial tills inherently contain cobbles and boulders.

5.9 Sand and Gravel to Gravelly Sand

A deposit of sand and gravel to gravelly sand was encountered beneath the lower silty clay in Boreholes PCT-02 and PCT-04. This layer was 0.8 and 1.7 m thick and overlies bedrock at depths of 10.3 and 9.8 m (Elev. 213.7 to 212.2 m).

An SPT N-value of 30 blows for 0.3 m penetration was recorded at the upper boundary of the sand and gravel in Borehole PCT-02, indicating a compact to dense condition. A single SPT N-value of 11 blows per 0.3 m of penetration was recorded in Borehole PCT-04, indicating a compact relative density. Moisture contents of 10 and 17% were measured in this deposit.

One sample of the deposit was selected for laboratory grain size analysis testing. The results of the test are summarized below and are presented on the corresponding Record of Borehole sheet included in Appendix A. The grain size distribution curve for the sample is plotted on Figure B6 of Appendix B.

Gravel %	21
Sand %	72
Silt and Clay %	7

5.10 Bedrock

Bedrock was proven in all four boreholes by coring 2.5 to 3.5 m into the bedrock. The depths and elevations of the bedrock surface encountered in the boreholes are summarized in Table 5.1.

Table 5.1 – Depths and Elevations of Bedrock Surface

Borehole	Bedrock Surface Proven by Coring	
	Depth (m)	**Elevation (m)**
PCT-01	9.2	213.3
PCT-02	10.3	213.7
PCT-03	11.2	212.8
PCT-04	9.8	212.2

The bedrock was described as dark grey migmatitic gneiss with white bands. The total core recovery (TCR) ranged from 97 to 100% and the rock quality designation (RQD) varied between 84 and 100%, indicating a good to excellent rock quality. The fracture index (FI) of the rock, expressed as fractures per 0.3 m of core, ranged from 0 to 5.

The estimated unconfined compressive strength (UCS) of the rock, interpreted from the results of point load tests, varied from 114 to 251 MPa, indicating a very strong strength classification.

5.11 Water Levels

Standpipe piezometers were installed in two boreholes to monitor groundwater levels after completion of drilling. A summary of the recorded groundwater levels is provided below.

Table 5.2 - Groundwater Level Measurements

Borehole	Date	Groundwater Level		Comment
		Depth (m)	Elevation	
PCT-01	June 8, 2014	0.8	221.7	In piezometer
	June 9, 2014	0.9	221.6	
	June 10, 2014	1.0	221.5	
	June 12, 2014	1.2	221.4	
PCT-04	June 9, 2014	0.2	221.8	In piezometer
	June 10, 2014	0.3	221.7	
	June 12, 2014	0.3	221.7	

The recorded groundwater levels are considered short-term readings and seasonal fluctuations of the groundwater level are to be expected, particularly after spring snowmelt as well as periods of prolonged and/or significant precipitation.

The groundwater level is also expected to be influenced by the water level in the Pagwachuan River Tributary, which is shown on the preliminary drawings provided by MMM to be at Elev. 222.4 at the outlet in April 2011.

6 MISCELLANEOUS

In general, the borehole locations were positioned in the field by Thurber staff and were established relative to site features. The co-ordinates and ground surface elevations at the boreholes were inferred from the MMM Group Limited General Arrangement drawing dated March 2014.

Eastern Ontario Diamond Drilling Limited from Hawkesbury, Ontario supplied a track mounted CME 55 drill rig and conducted the drilling, sampling and in-situ testing operations.

Full time supervision of the field activities was carried out by Mr. Matthew Whalen of Thurber. Overall supervision of the field program was conducted by Mr. Mark Farrant, P. Eng.

Interpretation of the data and preparation of this report were carried out by Mr. Michael Eastman and Mr. Murray R. Anderson, P.Eng. The report was reviewed by 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 INTRODUCTION

This report presents interpretation of the geotechnical data provided in the factual report and presents discussions and geotechnical design recommendations for replacement of the Pagwachuan River Tributary culvert on Highway 11 in the District of Thunder Bay, Ontario.

The existing Pagwachuan River Tributary culvert consists of a 25.5 m long timber culvert with twin 2.1 by 1.75 m openings. The river flows in a north to south direction at the site. The existing highway embankment at the crossing is approximately 2.1 m high.

The preliminary GA drawing (July 2014) indicates that the proposed replacement structure will consist of two parallel sheet pile walls and a precast concrete panel cap. The culvert span will be 9.0 m wide and the length will be 30.0 m, of which 18.0 m will be capped. The top of the river stone substrate will be at approximate Elev. 222.1 to 221.6 m. The clear height within the culvert will be approximately 1.0 m, and the fill height above the concrete panels will be approximately 0.7 m. The finished road grade will be near elevation 224.1 m.

The discussions and recommendations presented in this report are based on the factual data obtained during the course of the investigation. The preliminary General Arrangement drawing used for preparation of this report was provided by MMM Group Limited.

8 CULVERT FOUNDATION

8.1 General

In general, the subsurface stratigraphy encountered at the culvert site consisted of existing embankment fill overlying thin layers of sand and silty clay, underlain by deposits of silt to sandy silt and silty clay. The silty clay was underlain by discontinuous units of silty clay till and sand and gravel overlying bedrock contacted at depths of 9.2 to 11.2 m (Elev. 213.7 to 212.2). Peaty topsoil was encountered at the ground surface in the off-road boreholes, and a thin layer of buried peat was identified below the embankment fill.

Groundwater levels measured in standpipe piezometers installed at the site ranged from Elev. 221.4 to 221.8 m. The preliminary GA drawing indicates a water level at Elev. 222.4 m in Pagwachuan River Tributary in April 2011.

8.2 Selection of Culvert Type

We understand that a sheet pile wall design was selected as the preferred culvert type for considerations other than the geotechnical conditions on site. From a geotechnical perspective, the proposed culvert design is considered to be suitable.

Geotechnical recommendations for the proposed sheet pile culvert design are provided below. The culvert must be designed for static and seismic conditions to resist external loadings including lateral earth pressures, hydrostatic pressure, weight of embankment fill, traffic loading and any surcharge due to construction equipment and activities.

Potential alternatives to the sheet pile design include a concrete box culvert placed on the native silty clay or an arch/open footing culvert supported on piles. The geotechnical resistance of the native silt and silty clay is considered inadequate for the use of spread footings and therefore an arch/open footing culvert on footings is not recommended. A comparison of alternative culvert/foundation systems, based on advantages and disadvantages of each, is included in Appendix D. The alternative systems were not developed further.

8.3 Steel Sheet Pile Culvert

In view of the low geotechnical resistance available in the foundation soils, it is recommended that the sheet piles be driven to refusal on the underlying bedrock. Based on the borehole information, the recommended sheet pile tip elevation and pile lengths are as shown in Table 8.1 below:

Table 8.1 – Recommended Tip Elevation and Pile Lengths of Sheet Piles

Borehole	Bedrock Elevation	Estimated Sheet Pile Length(1) (m)
PCT-01	213.3	9.7
PCT-02	213.7	9.3
PCT-03	212.8	10.2
PCT-04	212.2	10.8

Note: (1) Based on top of sheet pile Elevation 223.0 m as shown on preliminary GA drawing.

The resistance of sheet piles driven to refusal on unyielding bedrock will be controlled by the structural capacity of the selected sheet pile section. For EZ88 sheet piles (section area 135 cm^2/m and steel yield strength of 350 kPa), the recommended geotechnical resistance at factored ULS (per linear meter) is 1300 kN. This resistance includes a reduction to account for subsurface uncertainties.

The SLS capacity will not govern for steel piles driven to bedrock.

Steel sheet pile installation should be in accordance wirh OPSS 903. The appropriate pile driving note is "SHEET PILES TO BE DRIVEN TO BEDROCK".

Sheet piles should be provided with tip protection to minimize tip damage when setting on bedrock and while driving through the sand and gravel and gravelly sand layers with possible cobbles and boulders above the bedrock surface.

Rock erosion protection is present adjacent to the existing culvert outlet. This material must be removed prior to driving of sheet piles.

Design of the permanent sheet pile walls must consider environmental conditions such as road salts and fluctuating water levels that may cause corrosion and reduce the service life of the structure. The native soils in front of the sheet pile should be protected from creek erosion so that the sheet piles do not lose lateral support.

8.3.1 Downdrag

Downdrag on the sheet piles is not considered to be an issue at this site since there is no proposed grade raise.

8.3.2 Sheet Pile Lateral Resistance

Design for lateral resistance of the sheet piles may be carried out using the earth pressure coefficients (K_a = active, K_o = at rest, K_p = passive) and soil unit weights provided in Table 8.2 below and Table 9.1 in Section 9.

The interaction between the sheet pile wall and the adjacent soil may be analysed using a soil-spring model and a coefficient of horizontal subgrade reaction, k_s. The value of k_s for cohesive soils is shown in the table below and may be assumed to be constant with depth. In cohesionless soils, the horizontal subgrade reaction per linear meter varies with depth and can be calculated as follows:

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

where z = depth of embedment of pile in metres

n_h = coefficient related to soil density, see table below (kN/m^3)

Table 8.2 – Parameters for Estimating Lateral Pile Resistance

Alignment	Elevation	K_a	K_o	K_p	k_s (kPa/m)	n_h (kN/m³)	Unit Weight(1) (kN/m³)	Soil Type
West Sheet Pile Wall	224.0 to 222.4	0.31	0.47	3.3		5,000	20	Embankment Fill
	222.4 to 221.7	0.31	0.47	3.3		2,750	10	Embankment Fill
	221.7 to 218.4	0.35	0.52	2.9		1,250	9	Silt, Silty Clay and Sand
	218.4 to 214.5	0.44	-	2.3	1,300		9	Silty Clay
	214.5 to 213.7	0.28	-	3.5		6,000	10	Sand & Gravel
East Sheet Pile Wall	224.0 to 222.4	0.31	0.47	3.3		5,000	20	Embankment Fill
	222.4 to 221.4	0.31	0.47	3.3		2,750	10	Embankment Fill
	221.4 to 217.5	0.35	0.52	2.9		1,250	9	Silt, Silty Clay and Sand
	217.5 to 212.8	0.44	-	2.3	1,300		9	Silty Clay

Note: (1) submerged unit weight below water level.

For soil-spring analysis, the spring constant, K_s, may be obtained by the expression $K_s = k_s L$ (kN/m), where k_s is the coefficient of horizontal subgrade reaction (kN/m^3) and L is the length (m) of the pile segment or element used in the analysis.

8.4 Frost Cover

The design depth of frost penetration at this site is 2.5 m. The base of all foundation elements must be provided with a minimum of 2.5 m of earth cover as protection against frost action.

9 CULVERT BACKFILL AND LATERAL EARTH PRESSURES

Culvert backfill should consist of granular material conforming to OPSS.PROV 1010 Granular A, Granular B Type II or Granular B Type III specifications. Backfilling to the culvert should be in accordance with OPSS 902. Rock fill should not be used adjacent to the sheet pile wall.

Backfill should be placed and compacted in simultaneous equal lifts on both sides of the culvert, and the top of backfill elevation should be within 400 mm on both sides of the culvert at all times. The precast concrete cap panels must be in place prior to backfilling. Heavy compaction equipment should not be used adjacent to the walls and roof of the culvert. Compaction equipment to be used adjacent to culverts should be restricted in accordance with OPSS 501 and SP 105S21.

Lateral earth pressures acting on the culvert walls and wing walls may be assumed to be triangularly distributed and to be governed by the characteristics of the abutment backfill and the underlying soils. For a fully drained condition, the pressures should be computed in accordance with the CHBDC but generally are 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)

Earth pressure coefficients for backfill to the culvert and wingwalls are dependent on the material used as backfill and the inclination of the ground surface behind the wall. Recommended values are shown in Table 9.1.

Table 9.1 - Earth Pressure Coefficients

Condition	Earth Pressure Coefficient (K)			
	OPSS Granular A or OPSS Granular B Type II $\phi = 35°, \gamma = 22.8$ kN/m^3		OPSS Granular B Type I/III or Existing Sand & Gravel Fill $\phi = 32°, \gamma = 21.2$ kN/m^3	
	Horizontal Surface	Sloping Surface behind Wall (2H:1V)	Horizontal Surface	Sloping Surface behind Wall (2H:1V)
Active (Unrestrained Wall)	0.27	0.40	0.31	0.48
At rest (Restrained Wall)	0.43	-	0.47	-
Passive (Movement Towards Soil Mass)	3.7	-	3.3	-

* Use submerged unit weight below groundwater level.

The use of a material with a high friction angle and low active pressure coefficient (Granular A or Granular B Type II) is preferred as it results in lower earth pressures acting on the culvert.

The parameters in the tables correspond to full mobilization of active and passive earth pressures, and require certain relative movements between the wall and adjacent soil to produce these conditions. The values to be used in design can be assessed from Figure C6.16 of the Commentary to the CHBDC. Active pressures should be used for any wingwalls or unrestrained walls.

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 Type III or at a depth of 1.7 m for Granular A or Granular B Type II.

10 SEISMIC CONSIDERATIONS

The following seismic parameters should be used for design:

- Velocity Related Seismic Zone 0
- Zonal Velocity Ratio 0.0
- Acceleration Related Seismic Zone 0
- Zonal Acceleration Ratio 0.0
- Peak Horizontal Acceleration 0.019g

The soil profile type at this site has been classified as Type III. Therefore, according to Clause 4.4.6 of the CHBDC, a Site Coefficient "S" (ground motion amplification factor) of 1.5 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 10.1 may be used.

Table 10.1 - Earth Pressure Coefficients for Earthquake Loading

Condition	Earth Pressure Coefficient (K)		
	OPSS Granular A or OPSS Granular B Type II $\phi = 35°, \gamma = 22.8$ kN/m^3	**OPSS Granular B Type I/III or Existing Fill $\phi = 32°, \gamma = 21.2$ kN/m^3**	**Silt or Silty Clay $\phi = 23°$ $\gamma = 9$ kN/m^3**
Active (K_{AE})*	0.28	0.32	0.45
Passive (K_{PE})	3.70	3.20	2.30
At Rest (K_{OE})**	0.45	0.50	0.64

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

The silty clay and underlying dense to very dense cohesionless soils at this site are not prone to liquefaction. Portions of the silt layer may be susceptible to liquefaction. In view of the velocity related seismic zone of zero, liquefaction is not considered to be a concern at this site.

11 SCOUR PROTECTION AND EROSION CONTROL

Scour and erosion protection should be provided for the culvert channel as well as at the inlet and outlet areas. Design of the scour and erosion protection measures must consider hydrologic and hydraulic concerns and should be carried out by specialists experienced in this field.

Typically, rock protection should be provided over all earth surfaces with which stream flow is likely to be in contact. A vegetation cover should be established on all other exposed earth surfaces to protect against surficial erosion, in general accordance with OPSS 804.

12 EXCAVATION AND GROUNDWATER CONTROL

All excavation 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 soils at this site are classified as Type 3 soils above the water level and Type 4 soils below the water level.

The excavation and backfilling for foundations must be carried out in accordance with OPSS 902.

Excavation for installation of the proposed sheet pile wall culvert is expected to be limited to the existing highway embankment for placement of the cap panels and excavation between the sheet pile walls for channel construction. In general, this excavation will be carried out within embankment fill above the groundwater level.

Excavation will extend below the water level for channel construction and placement of the river stone substrate between the sheet pile walls. Excavation must be carried out in a manner that minimizes sloughing and disturbance of the subgrade on which the substrate will be placed. Relatively flat side slopes will be required for any unsupported excavation sidewalls.

Selection of the equipment and methodology to excavate and prepare the subgrade is the responsibility of the Contractor. The design of the shoring and dewatering system that may be required is also the responsibility of the Contractor and the Contract Documents must alert him to this responsibility.

Roadway protection will be required during various stages of construction. Roadway protection should be provided in accordance with OPSS 539 and designed for Performance Level 2. The design of roadway protection is the responsibility of the Contractor and all shoring should be designed by a Professional Engineer experienced in such designs.

13 CONSTRUCTION CONCERNS

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

- Cobbles or other buried obstructions may be encountered during excavation in the existing embankment fill or interfere with driving of sheet piles.
- The sheet piles may encounter refusal at varying depths on possible cobbles or boulders in the sand and gravel layer underlying the silty clay.
- The water levels in the creek may fluctuate.

- The Contractor's selection of construction equipment and methodology must include assessment of the capability of the existing embankment to support the proposed construction equipment and any temporary structures or fill (i.e, as a pad for crane support). Site conditions may limit the type of equipment suitable for use. The design and safety of any temporary works is the responsibility of the Contractor.

14 CLOSURE

Engineering analysis and preparation of the report were carried out by Mr. Stephen Peters, P.Eng. and Mr. Murray Anderson, P.Eng. The report was reviewed by Dr. P.K. Chatterji, P.Eng., a Designated Principal Contact for MTO Foundations Projects.

Thurber Engineering Ltd.

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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.

UNIFIED SOILS CLASSIFICATION

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			

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.

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No PCT-01

METRIC

WP# 6134-11-01 | LOCATION Pagwachuan River Tributary Culvert N 5 515 454.8 E 411 164.4 | ORIGINATED BY MNW

HWY 11 | BOREHOLE TYPE NW Casing & Wash Boring | COMPILED BY AN

DATUM Geodetic | DATE 2014.06.07 - 2014.06.07 | CHECKED BY MEF

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
222.5	(ground surface)
0.0	**TOPSOIL**, peaty Dark Brown
222.0 / 0.5	**SAND**, trace silt, with organics Very Loose Brown Moist
0.2	Silty **CLAY**, trace sand Firm Greyish Brown
220.8 / 1.7	Silty **SAND**, some gravel Loose Dark Brown Wet
220.5 / 2.0	**SILT**, some clay, trace sand, with clay seams Loose Light Brown
218.4 / 4.1	Silty **CLAY**, trace sand, trace gravel, with silt seams Stiff Brown
214.7 / 7.8	Silty **CLAY**, trace sand, trace gravel Stiff Brown (TILL)
213.3 / 9.2	**BEDROCK: MIGMATITIC GNEISS**, dark grey, with white bands and occasional fractures

SAMPLES

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
1	SS	3	
2	SS	5	
3	SS	8	13 62 25 (SI+CL)
4	SS	7	0 6 78 16
5	SS	6	
6	SS	5	
7	SS	2	2 4 45 49
8	SS	11	
9	SS	50/ 0.075	
1	RUN		RUN #1 TCR=100% SCR=100% RQD=84% UCS=115MPa (Average)

Field vane shear strength (sensitivity): 10.0 at approx. elev. 216.9; 2.0 at approx. elev. 215.5.

UNIT WEIGHT column: FI 0, 1

Ground water level indicated at approx. elev. 221.5.

ELEVATION SCALE: 222, 221, 220, 219, 218, 217, 216, 215, 214, 213

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 PCT-01

METRIC

WP# 6134-11-01	LOCATION Pagwachuan River Tributary Culvert N 5 515 454.8 E 411 164.4	ORIGINATED BY MNW
HWY 11	BOREHOLE TYPE NW Casing & Wash Boring	COMPILED BY AN
DATUM Geodetic	DATE 2014.06.07 - 2014.06.07	CHECKED BY MEF

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	ELEVATION SCALE	UNIT WEIGHT	REMARKS
	Continued From Previous Page						2	
							2	
						212	0	RUN #2 TCR=100% SCR=100% RQD=98% UCS=161MPa (Average)
			2	RUN			1	
							0	
						211	1	
							2	
			3	RUN			1	RUN #3 TCR=100% SCR=100% RQD=100% UCS=157MPa (Average)
						210	1	
209.8 12.7	END OF BOREHOLE AT 12.7m. Piezometer installation consists of 19mm diameter Schedule 40 PVC pipe with a 1.52m slotted screen.						1	

WATER LEVEL READINGS:

DATE	DEPTH (m)	ELEV. (m)
2014.06.08	0.8	221.7
2014.06.09	0.9	221.6
2014.06.10	1.0	221.5
2014.06.12	1.2	221.3

+ 3, × 3: Numbers refer to Sensitivity

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

RECORD OF BOREHOLE No PCT-02

METRIC

WP#	6134-11-01	LOCATION	Pagwachuan River Tributary Culvert N 5 515 442.7 E 411 153.0	ORIGINATED BY	MNW
HWY	11	BOREHOLE TYPE	NW Casing & Wash Boring	COMPILED BY	AN
DATUM	Geodetic	DATE	2014.06.10 - 2014.06.10	CHECKED BY	MEF

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
224.0 / 0.0	**ASPHALT:** (100mm)
0.1	**SAND** and **GRAVEL**, trace silt, Very Dense, Dark Brown, Moist (FILL)
223.5 / 0.5	**SAND**, some gravel, trace silt, Compact to Loose, Light Brown, Moist (FILL)
221.7 / 2.3	**PEAT**, Soft, Dark Brown, Wet
221.5 / 2.5	Silty **CLAY**, trace sand, trace gravel, Soft, Brownish Grey
220.7 / 3.3	**SAND**, some gravel, some silt, Compact, Greyish Brown, Wet
219.9 / 4.1	**SILT**, some clay, trace sand, with clay seams, Compact, Greyish Brown
218.4 / 5.6	Silty **CLAY**, trace sand, with silt seams, Soft to Firm, Dark Brown
214.5 / 9.5	**SAND** and **GRAVEL**, trace silt, Dense, Dark Brown

SAMPLES

NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
1	SS	54				
2	SS	24				
3	SS	8	15	71	14 (SI+CL)	
4	SS	3				
5	SS	11	20	63	17 (SI+CL)	
6	SS	19				
7	SS	3				
8	SS	0	0	0	34	66
9	SS	30				

Columns: GROUND WATER CONDITIONS; ELEVATION SCALE (223, 222, 221, 220, 219, 218, 217, 216, 215); 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).

Field vane readings: 4.0 (at approx. elev. 217); 5.0 (at approx. elev. 215.6). Water content 391 (PEAT).

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 PCT-02

METRIC

WP#	6134-11-01	LOCATION	Pagwachuan River Tributary Culvert N 5 515 442.7 E 411 153.0	ORIGINATED BY	MNW
HWY	11	BOREHOLE TYPE	NW Casing & Wash Boring	COMPILED BY	AN
DATUM	Geodetic	DATE	2014.06.10 - 2014.06.10	CHECKED BY	MEF

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	GROUND WATER CONDITIONS	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%)
	Continued From Previous Page							
213.7	Wet							
10.3	**BEDROCK: MIGMATITIC GNEISS**, dark grey, with white bands and occasional fractures		1	RUN				RUN #1 TCR=100% SCR=100% RQD=100% UCS=231MPa (Average)
							213	
			2	RUN				RUN #2 TCR=97% SCR=93% RQD=88% UCS=187MPa (Average)
							212	
			3	RUN				RUN #3 TCR=100% SCR=100% RQD=90% UCS=222MPa (Average)
							211	
210.3								
13.7	END OF BOREHOLE AT 13.7m. BOREHOLE BACKFILLED WITH BENTONITE HOLEPLUG TO 0.6m, CONCRETE TO 0.1m, THEN COLD PATCH TO SURFACE.							

ONTMT4S 1197.GPJ 2012TEMPLATE(MTO).GDT 8/13/14

+ 3, × 3: Numbers refer to Sensitivity

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

RECORD OF BOREHOLE No PCT-03

METRIC

WP#	6134-11-01	LOCATION	Pagwachuan River Tributary Culvert N 5 515 438.8 E 411 163.7	ORIGINATED BY	MNW
HWY	11	BOREHOLE TYPE	NW Casing/NQ Coring	COMPILED BY	AN
DATUM	Geodetic	DATE	2014.06.09 - 2014.06.09	CHECKED BY	MEF

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)

Ground surface elevation: 224.0

ELEV / DEPTH	DESCRIPTION
0.0	**ASPHALT:** (125mm)
0.1	**SAND** and **GRAVEL**, trace silt, Very Dense, Brown/Grey, Moist (FILL)
223.0 / 1.0	**SAND**, some gravel, trace silt, Compact, Brown, Wet (FILL)
221.4	Thin organic layer
2.6	Silty **CLAY**, trace sand, trace gravel, Stiff, Greyish Brown
221.0 / 3.0	**SAND**, some gravel to gravelly, some silt, Compact, Dark Grey, Wet
220.6 / 3.4	Sandy **SILT**, trace to some clay, trace gravel, Loose, Dark Greyish Brown, Wet
217.5 / 6.5	Silty **CLAY**, with silt seams, Soft to Firm, Dark Brown

NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
1	SS	67	36	57	7 (SI+CL)	
2	SS	19				
3	SS	11				
4	SS	22				
5	SS	13	26	54	20 (SI+CL)	
6	SS	8	2	32	58	8
7	SS	9	0	38	50	12
8	SS	1				
9	SS	1	0	0	59	41

Elevation scale: 223, 222, 221, 220, 219, 218, 217, 216, 215

Field vane shear strength (approx. elev. 215.6): 6.0

Continued Next Page

+ ³, × ³: Numbers refer to Sensitivity

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

RECORD OF BOREHOLE No PCT-03

METRIC

WP#	6134-11-01	LOCATION	Pagwachuan River Tributary Culvert N 5 515 438.8 E 411 163.7	ORIGINATED BY	MNW
HWY	11	BOREHOLE TYPE	NW Casing/NQ Coring	COMPILED BY	AN
DATUM	Geodetic	DATE	2014.06.09 - 2014.06.09	CHECKED BY	MEF

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	SHEAR STRENGTH kPa	UNIT WEIGHT (FI)	REMARKS & GRAIN SIZE DISTRIBUTION (%)
	Continued From Previous Page					3.0 (+)		
	with till layers	10	SS	16	213			
212.8 / 11.2	**BEDROCK: MIGMATITIC GNEISS**, dark grey, with white bands and occasional fractures	1	RUN		212		FI: 0, 0, 0, 0	RUN #1 TCR=100% SCR=100% RQD=100% UCS=114MPa (Average)
		2	RUN		211		3, 0, 0, 2	RUN #2 TCR=100% SCR=102% RQD=92% UCS=251MPa (Average)
209.5 / 14.5		3	RUN		210		0, 0, 0	RUN #3 TCR=100% SCR=100% RQD=100%
	END OF BOREHOLE AT 14.5m. BOREHOLE BACKFILLED WITH BENTONITE HOLEPLUG TO 0.6m, CONCRETE TO 0.1m, THEN ASPHALT COLD PATCH TO SURFACE.							

Legend: DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa: ○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE (20, 40, 60, 80, 100); PLASTIC LIMIT w_P, NATURAL MOISTURE CONTENT w, LIQUID LIMIT w_L; WATER CONTENT (%) (20, 40, 60); UNIT WEIGHT γ kN/m³; GR SA SI CL; GROUND WATER CONDITIONS; STRAT PLOT.

+ 3, × 3: Numbers refer to Sensitivity

15 ⊕ 5 (20 above, 10 below) (%) STRAIN AT FAILURE

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No PCT-04

METRIC

WP#	6134-11-01	LOCATION	Pagwachuan River Tributary Culvert N 5 515 425.3 E 411 151.2	ORIGINATED BY	MNW
HWY	11	BOREHOLE TYPE	NW Casing/NQ Coring	COMPILED BY	AN
DATUM	Geodetic	DATE	2014.06.08 - 2014.06.08	CHECKED BY	MEF

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	FIELD VANE (kPa)	WATER CONTENT	REMARKS / GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
222.0 / 0.0	**TOPSOIL**, peaty Dark Brown Wet						
221.7 / 0.3	Silty **CLAY**, trace sand, trace organics Very Soft Brown	1	SS	0			
221.2 / 0.8	**SILT**, some sand, trace clay, trace wood pieces Very Loose Dark Greyish Brown Wet	2	SS	1			
220.6 / 1.4	**SILT**, some clay, trace sand, trace gravel Loose to Compact Brownish Grey Moist	3	SS	10			
		4	SS	8			
219.0 / 3.0	Silty **CLAY**, trace sand, trace gravel Stiff Greyish Brown	5	SS	13		PL–w–LL	2 9 52 37
217.1 / 4.9	Silty **CLAY** Firm to Very Soft Greyish Brown	6	SS	5			
					4.0		
		7	SS	1		PL–w–LL	0 0 51 49
					3.0		
	with till layers	8	SS	4			
213.9 / 8.1	Gravelly **SAND**, trace silt Compact Dark Brown Wet	9	SS	11			21 72 7 (SI+CL)
212.2 / 9.8	**BEDROCK: MIGMATITIC GNEISS**,						FI 1; RUN #1 TCR=100%

Elevation scale: 221, 220, 219, 218, 217, 216, 215, 214, 213

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
Water Content (%): 20 40 60 (Plastic limit w_P, Natural moisture content w, Liquid limit w_L)
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 PCT-04

METRIC

WP#	6134-11-01	LOCATION	Pagwachuan River Tributary Culvert N 5 515 425.3 E 411 151.2	ORIGINATED BY	MNW
HWY	11	BOREHOLE TYPE	NW Casing/NQ Coring	COMPILED BY	AN
DATUM	Geodetic	DATE	2014.06.08 - 2014.06.08	CHECKED BY	MEF

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; 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										
	dark grey		1	RUN						2 2 5	SCR=95% RQD=86% UCS=168MPa (Average)
							211				
			2	RUN						1 0 0	RUN #2 TCR=98% SCR=98% RQD=98% UCS=201MPa (Average)
							210			2	
209.7										0	
12.3	END OF BOREHOLE AT 12.3m. Piezometer installation consists of 19mm diameter Schedule 40 PVC pipe with a 1.52m slotted screen. WATER LEVEL READINGS: DATE DEPTH (m) ELEV. (m) 2014.06.09 0.2 221.8 2014.06.10 0.3 221.7 2014.06.12 0.3 221.7										

ONTMT4S 1197.GPJ 2012TEMPLATE(MTO).GDT 8/13/14

+ ³, × ³: Numbers refer to Sensitivity

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

Appendix B

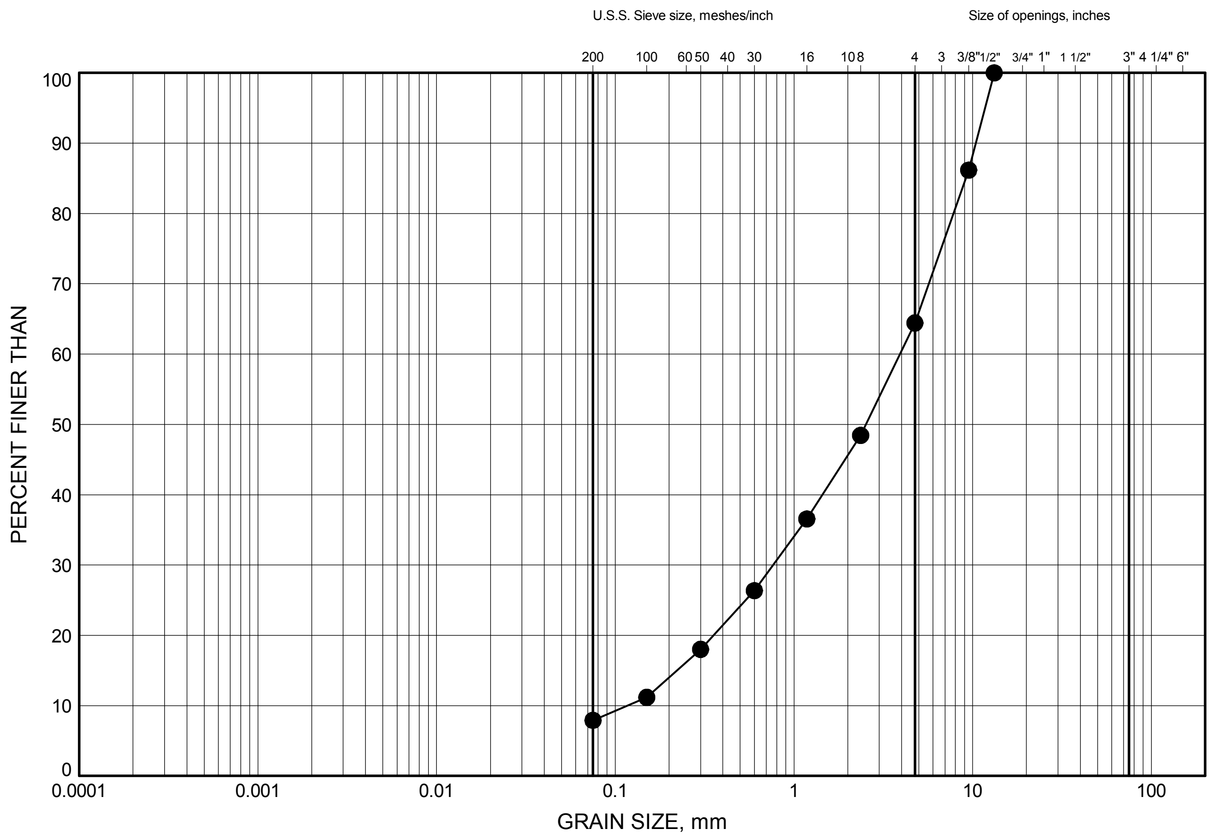
Laboratory Test Results

Pagwachuan River Tributary Culvert

GRAIN SIZE DISTRIBUTION

FIGURE B1

SAND & GRAVEL FILL



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	PCT-03	0.43	223.57

GRAIN SIZE DISTRIBUTION - THURBER 1197.GPJ 7/31/14

Date July 2014

WP# 6134-11-01

THURBER

Prep'd AN

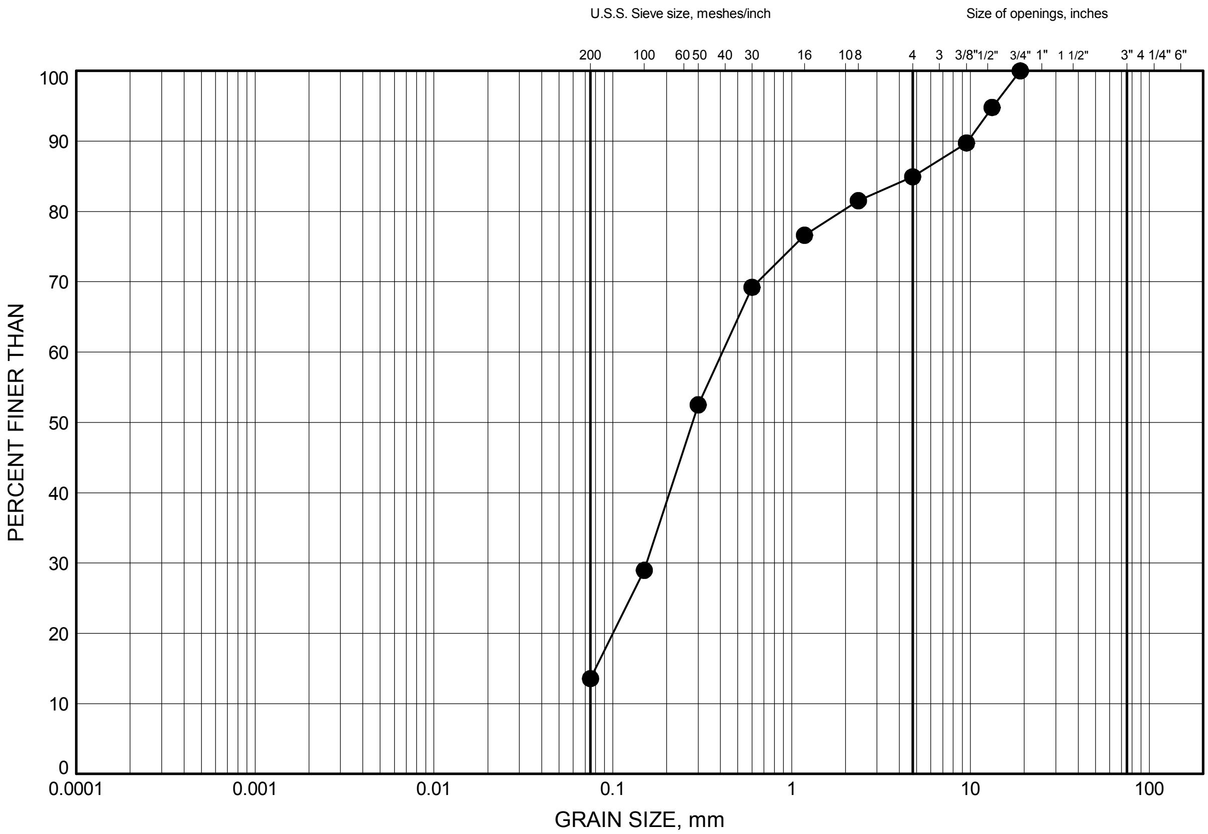
Chkd. MKE

Pagwachuan River Tributary Culvert

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)
●	PCT-02	1.83	222.17

GRAIN SIZE DISTRIBUTION - THURBER 1197.GPJ 7/31/14

Date July 2014

WP# 6134-11-01

THURBER

Prep'd AN

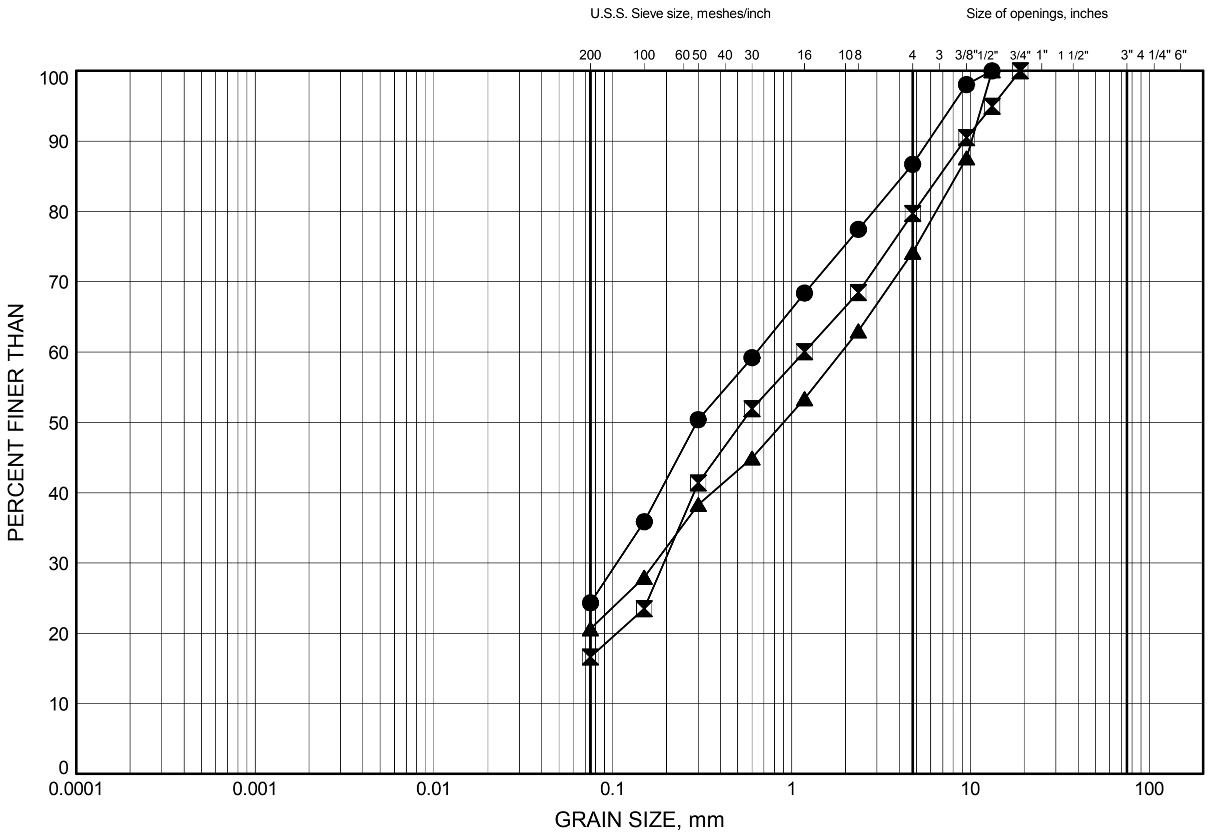
Chkd. MKE

Pagwachuan River Tributary Culvert

GRAIN SIZE DISTRIBUTION

FIGURE B3

SILTY SAND to SAND



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	PCT-01	1.98	220.52
⧗	PCT-02	3.47	220.53
▲	PCT-03	3.20	220.80

Date July 2014

WP# 6134-11-01

THURBER

Prep'd AN

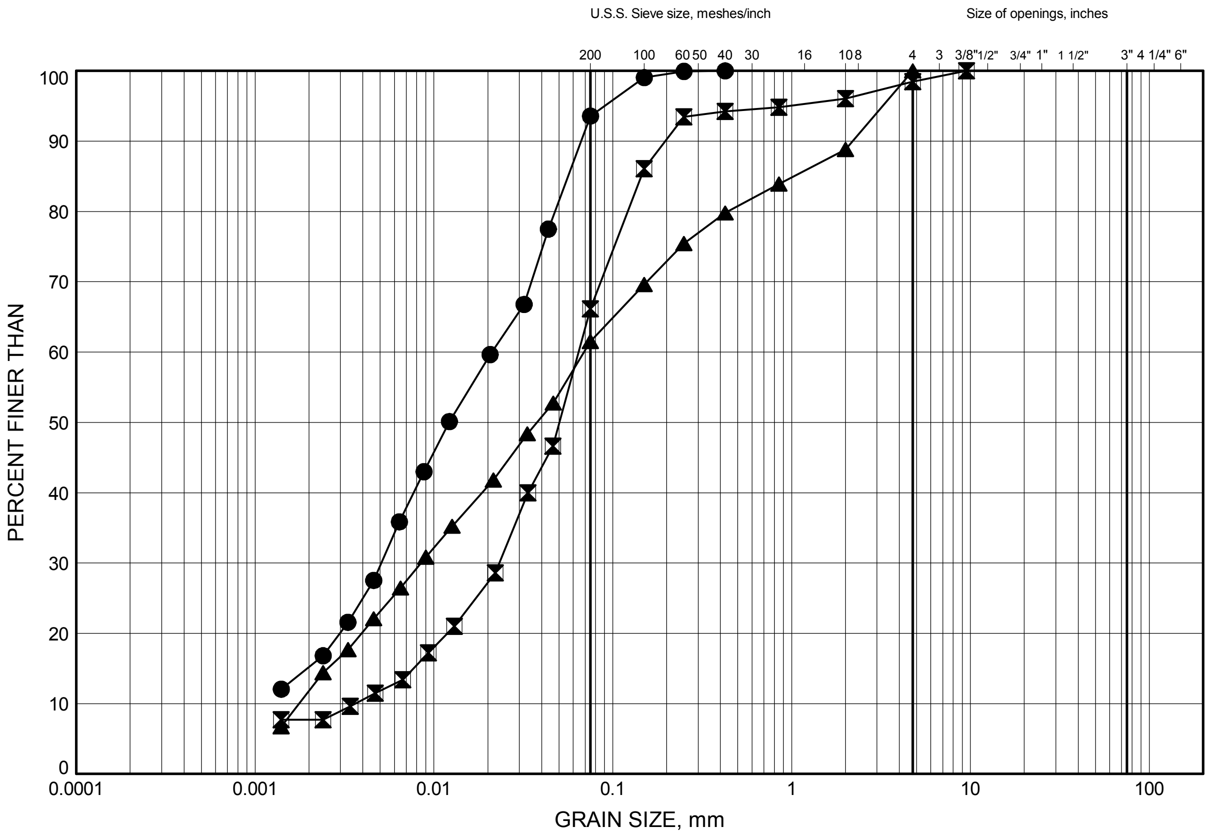
Chkd. MKE

Pagwachuan River Tributary Culvert

GRAIN SIZE DISTRIBUTION

FIGURE B4

SANDY SILT to SILT



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	PCT-01	2.59	219.91
⧗	PCT-03	4.72	219.28
▲	PCT-03	6.29	217.71

GRAIN SIZE DISTRIBUTION - THURBER 1197.GPJ 7/31/14

Date July 2014

WP# 6134-11-01

THURBER

Prep'd AN

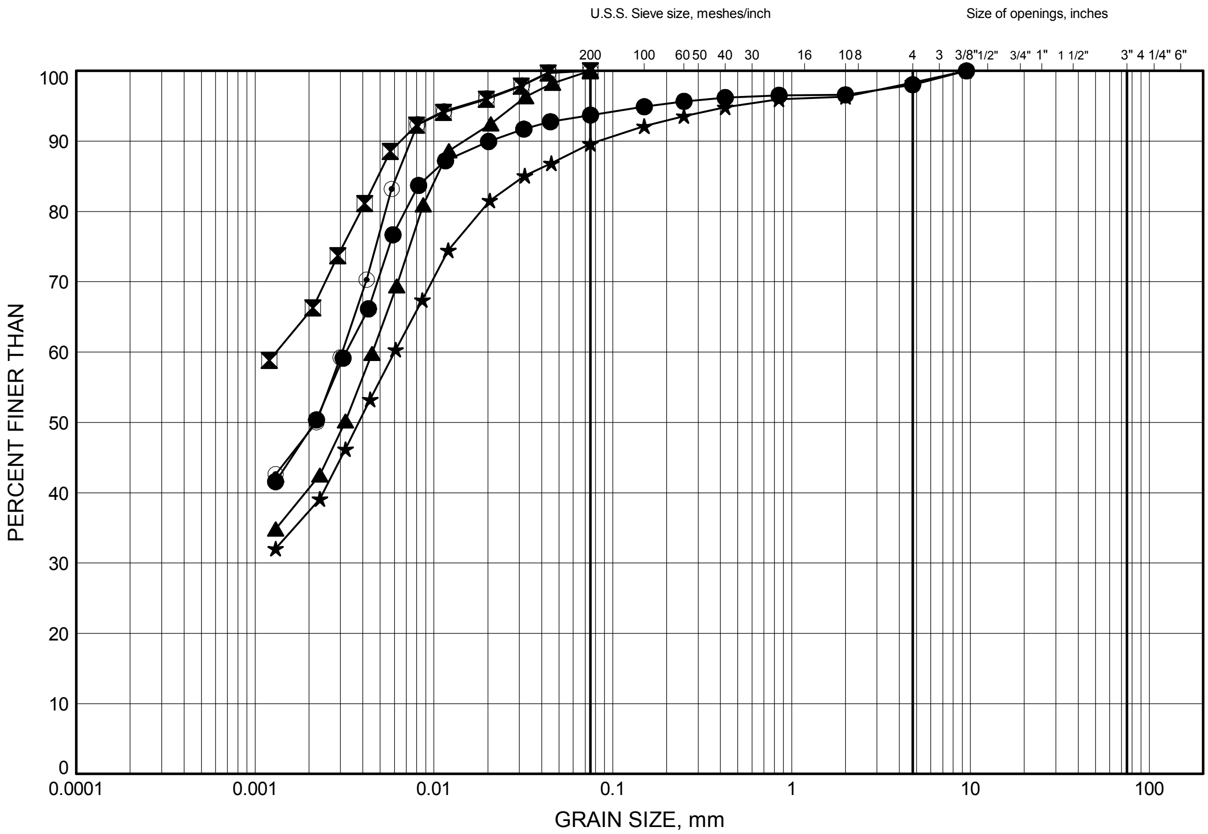
Chkd. MKE

Pagwachuan River Tributary Culvert

GRAIN SIZE DISTRIBUTION

FIGURE B5

SILTY CLAY to SILTY CLAY TILL



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	PCT-01	6.40	216.10
⧗	PCT-02	7.92	216.08
▲	PCT-03	9.45	214.55
★	PCT-04	3.28	218.72
⊙	PCT-04	6.40	215.60

Date July 2014

WP# 6134-11-01

THURBER

Prep'd AN

Chkd. MKE

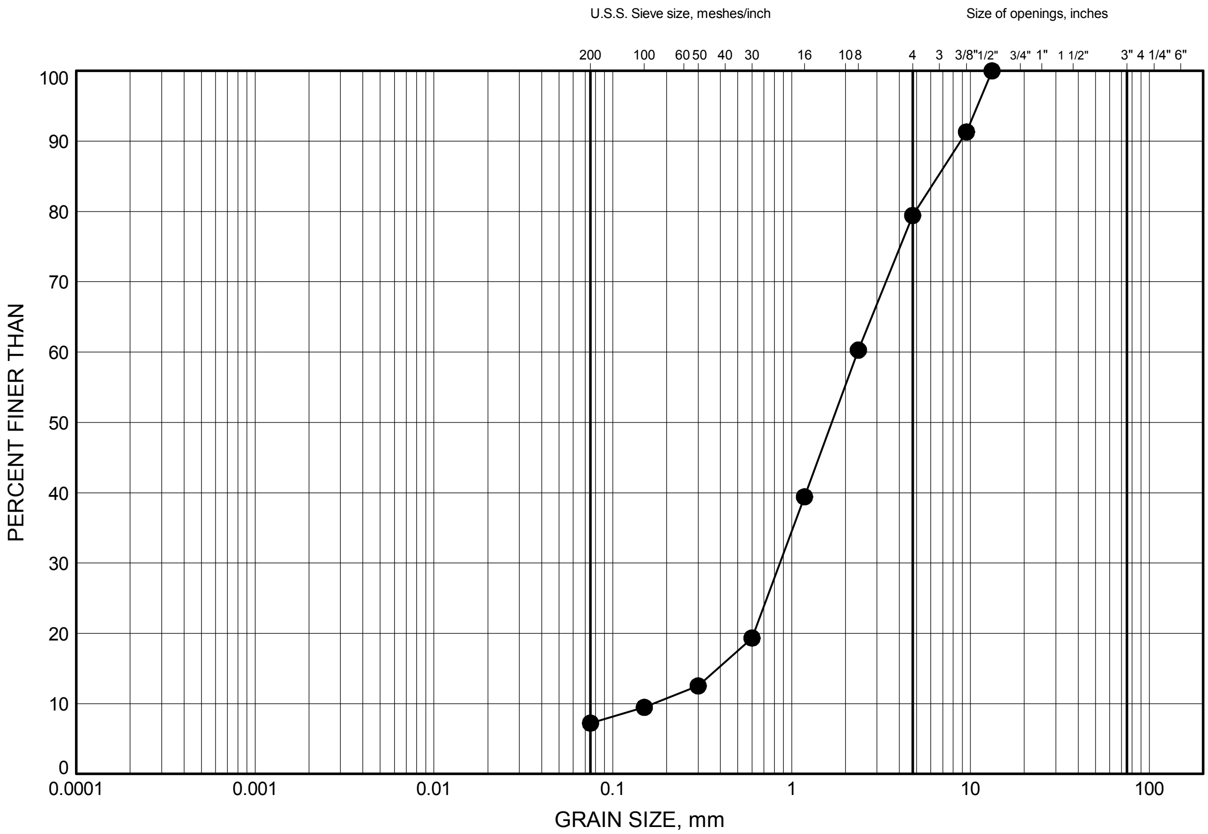
GRAIN SIZE DISTRIBUTION - THURBER 1197.GPJ 7/31/14

Pagwachuan River Tributary Culvert

GRAIN SIZE DISTRIBUTION

FIGURE B6

SAND & GRAVEL to GRAVELLY SAND



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	PCT-04	9.45	212.55

Date July 2014
WP# 6134-11-01

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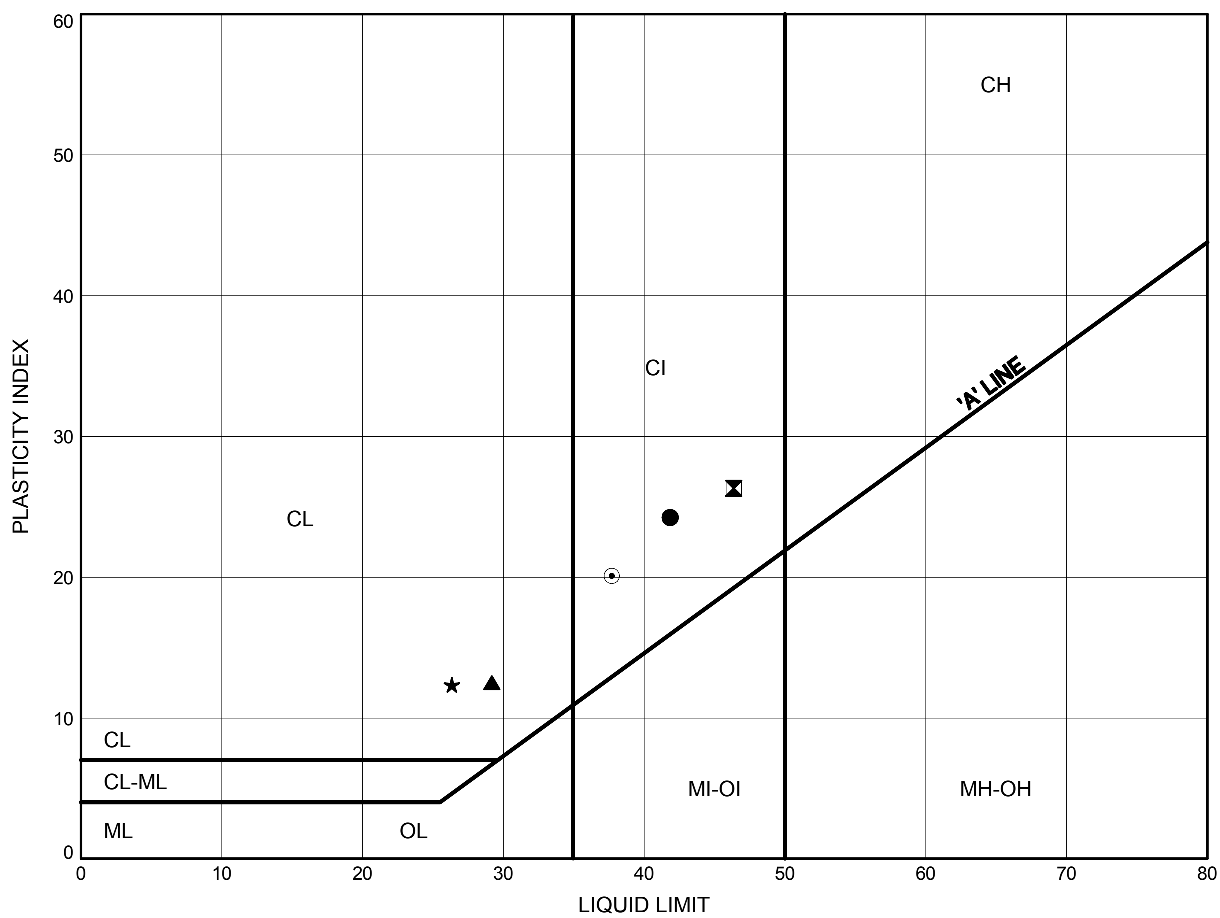
Pagwachuan River Tributary Culvert

ATTERBERG LIMITS TEST RESULTS

FIGURE B7

SILTY CLAY to SILTY CLAY FILL



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	PCT-01	6.40	216.10
⧗	PCT-02	7.92	216.08
▲	PCT-03	9.45	214.55
★	PCT-04	3.28	218.72
⊙	PCT-04	6.40	215.60

THURBALT 1197.GPJ 7/31/14

Date July 2014

WP# 6134-11-01

THURBER

Prep'd AN

Chkd. MKE

Appendix C

Site Photographs

THURBER

Photograph 1 – South end of culvert, looking east at culvert outlet and highway embankment

Photograph 2 – South end of culvert, looking northeast at culvert outlet

Photograph 3 – North end of culvert, looking northwest at culvert inlet and highway embankment

Photograph 4 – North end of culvert, looking southwest at culvert outlet

Appendix D

Foundation Comparison

COMPARISON OF CULVERT TYPE / FOUNDATION ALTERNATIVES

Concrete Box Culvert	Arch/Open Culvert on Footings	Arch/Open Culvert on Piles	Sheet Pile Culvert
Advantages: i. Typically least costly culvert type. ii. Conventional culvert design. iii. Ease of installation.	***Advantages:*** i. Relatively straightforward construction. ii. Less costly than pile or sheet pile options.	***Advantages:*** i. High geotechnical resistance is available for piles driven to very dense soil. ii. Settlement of culvert is not an issue. iii. Installation of piles could continue in freezing weather. iv. Reduced excavation below water level.	***Advantages:*** i. Ease of construction. ii. Potentially minimizes volume of excavation and roadway protection requirements. iii. Maintains water flow throughout construction. iv. Installation of piles could continue in freezing weather
Disadvantages: i. Excavation to place bedding material will extend below water level. ii. Maintenance of water flow may be an issue and require a sacrificial culvert. iii. Potential impact on fisheries.	***Disadvantages:*** i. Inadequate geotechnical resistance available in native soils. ii. Excavation for footing construction will extend below water level. iii. Potential for settlement in underlying silty clay under new culvert loads.	***Disadvantages:*** i. Higher cost than spread footings.	***Disadvantages:*** i. Large quantity and high cost of sheet piles. ii. Unconventional design.
FEASIBLE	**NOT RECOMMENDED**	**NOT RECOMMENDED**	**RECOMMENDED**

Appendix E

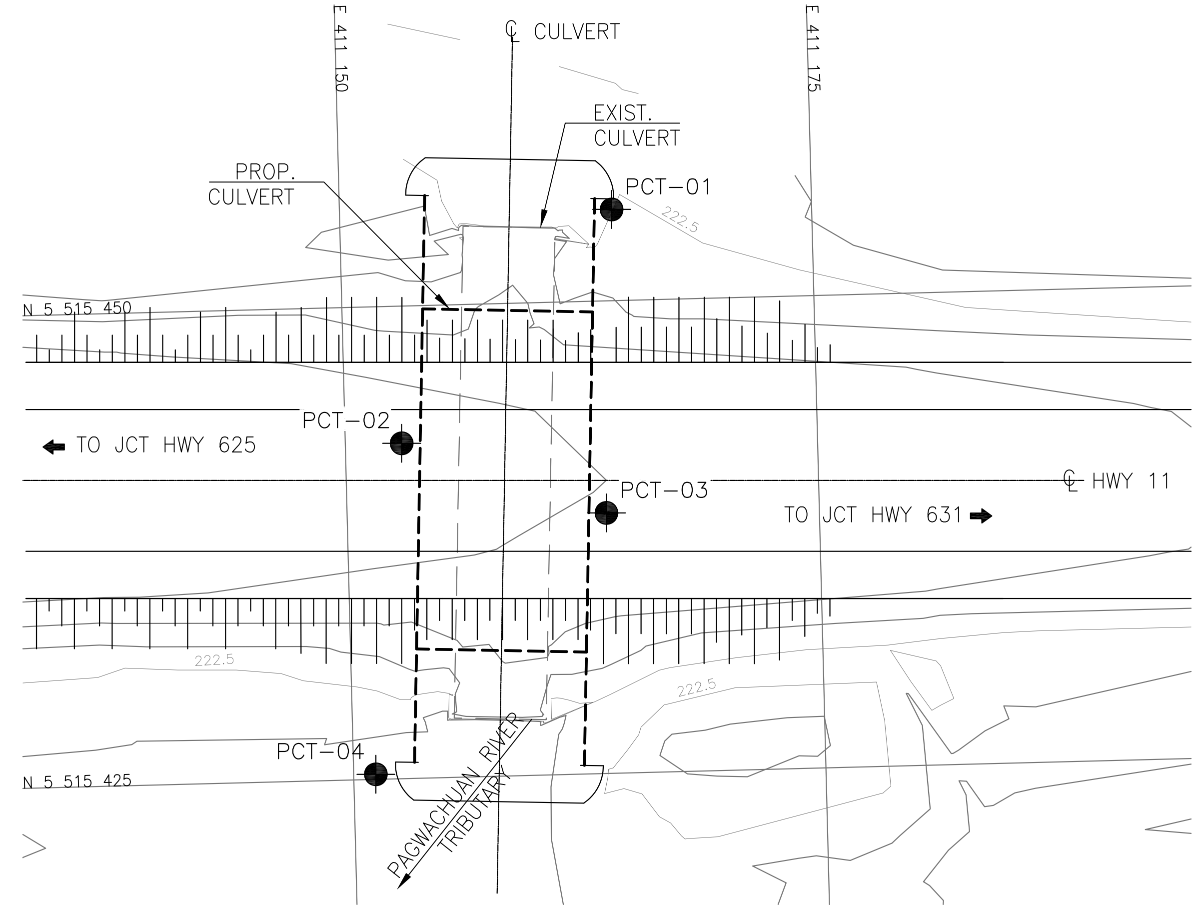
List of SPs and OPSS, and Suggested Text for Selected NSSP

1. List of Special Provisions and OPSS Documents Referenced in this Report:

- OPSS 501
- OPSS 539
- OPSS 804
- OPSS 902
- OPSS 903
- OPSS.PROV 1010
- SP 105S21

Appendix F

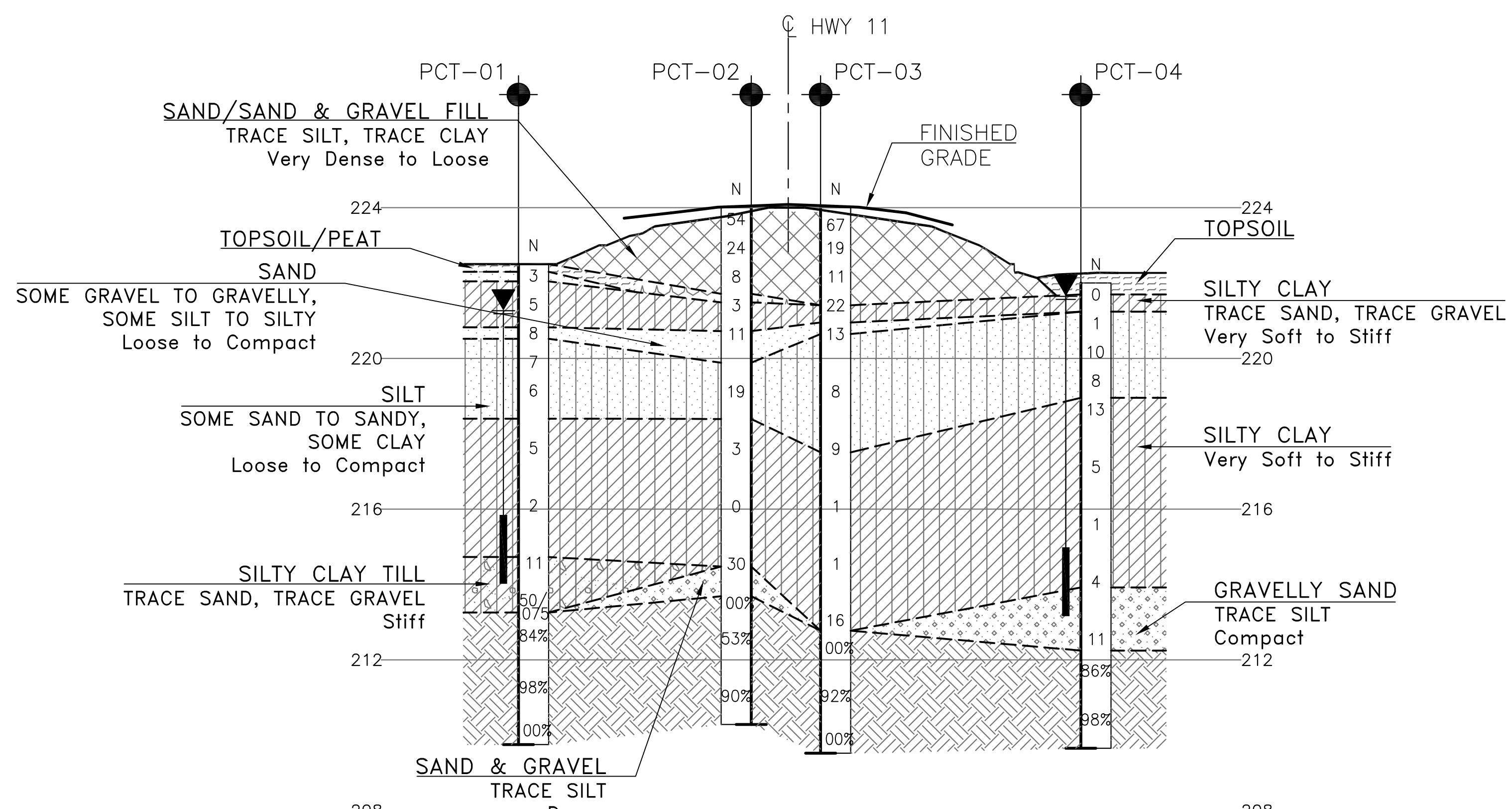
Borehole Locations and Soil Strata Drawing



PLAN

8 0 8 16m

SCALE 1:400



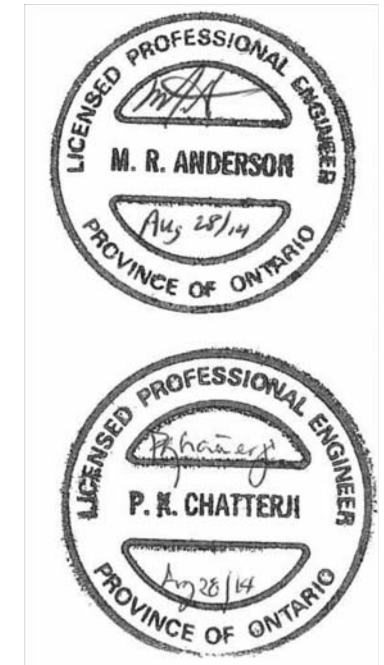
PROFILE ALONG ℄ CULVERT

8 0 8 16m H 1:400

4 0 4 8 V 1:200

METRIC

DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN



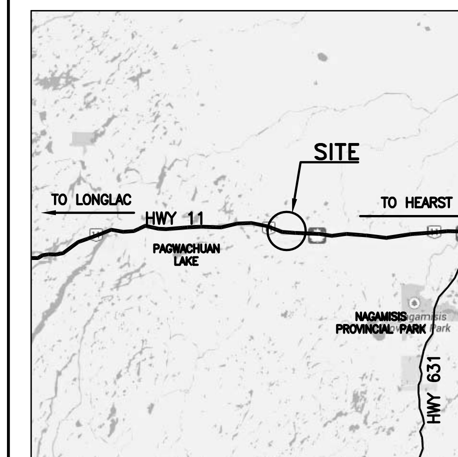
CONT No
WP No 6134–11–01

HIGHWAY 11
PAGWACHUAN RIVER TRIBUTARY
CULVERT REPLACEMENT
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET 27

MMM GROUP

THURBER ENGINEERING LTD.



KEYPLAN

LEGEND

●	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 During Drilling
⊻	Water Level In Piezometer
90%	Rock Quality Designation (RQD)
A/R	Auger Refusal

NO	ELEVATION	NORTHING	EASTING
PCT–01	222.5	5 515 454.8	411 164.4
PCT–02	224.0	5 515 442.7	411 153.0
PCT–03	224.0	5 515 438.8	411 163.7
PCT–04	222.0	5 515 425.3	411 151.2

-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. 42F-31

REVISIONS	DATE	BY	DESCRIPTION		
DESIGN MEF	CHK MEF	CODE	LOAD	DATE AUG 2014	
DRAWN AN	CHK	SITE 48E–69/C	STRUCT	DWG 2	

FILENAME: H:\Drafting\19\1351\197\ed1197-PagwachuanRiverTributary(Plan&Profile).dwg
PLOTDATE: 9/4/2014 1:26 PM