

**FOUNDATION INVESTIGATION AND DESIGN REPORT
CASH CREEK TRIBUTARY CULVERT
HIGHWAY 11, DISTRICT OF THUNDER BAY
G.W.P. 6932-10-00, STRUCTURE NO. 48C-188/C**

Geocres Number: 52H-17

**Report to
McCormick Rankin Corporation**

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PART 1: FACTUAL INFORMATION

1 INTRODUCTION

This report presents the factual findings obtained from a geotechnical investigation conducted at the location of a culvert carrying Highway 11 over the Cash Creek Tributary in the District of Thunder Bay, Ontario.

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

Thurber carried out the investigation as a sub-consultant to McCormick Rankin Corporation under the Ministry of Transportation Ontario (MTO) Agreement Number 6010-E-0011.

2 SITE DESCRIPTION

The site is located on Highway 11 approximately 18 km north of the intersection with Highway 17 in the Geographic Township of Ledger, District of Thunder Bay, Ontario.

Highway 11 at the existing culvert location is constructed on an approximate 10 m high embankment crossing a ravine carrying Cash Creek Tributary. The embankment slopes are grass covered with some trees growing on the lower parts of the slope. The surrounding lands are heavily wooded. The ground surface has a gently undulating topography.

Photographs 1 to 4 in Appendix C show views of the culvert site. The existing culvert is a rigid frame concrete culvert with a width of 2.9 m and a length of 46.1 m. The existing culvert has settled and cracked severely.

The site lies within the Canadian Shield, characterized by low, rounded hills of Pre-Cambrian bedrock mantled by varying thicknesses of overburden. At this site, the overburden primarily consists of glaciolacustrine silts and clays that are well sorted and well bedded to massive. The thickness of this geologic stratum is generally 1 to 3 m, locally greater than 30 m. The underlying bedrock consists of paragneiss and migmatite.



3 SITE INVESTIGATION AND FIELD TESTING

The site investigation and field testing for this project were carried out during the period January 12 to 19, 2011. A total of three sampled boreholes (numbered CC11-01 to CC11-03) were drilled adjacent to the existing culvert, from the top of the embankment to depths of 28.0 to 31.1 m. In addition, two Dynamic Cone Penetration Tests (DCPTs numbered CC11-04 and CC11-05) were advanced near the ends of the culvert to depths of 14.9 and 15.8 m.

The approximate locations of the boreholes and DCPTs are shown on the Borehole Locations and Soil Strata Drawing in Appendix E. The coordinates and elevations of the boreholes are given on the drawings and on the individual Record of Borehole Sheets in Appendix A.

Prior to commencement of drilling, utility clearances were obtained for all borehole locations.

Hollow stem augers and wash-boring with casing were used to advance the boreholes. Samples were obtained at selected intervals using a 50 mm diameter split spoon sampler in conjunction with Standard Penetration Testing (SPT). To supplement the SPT information, a DCPT test was also completed near Borehole CC11-02.

A member of Thurber's engineering staff supervised the drilling and sampling operations on a full time basis. The supervisor logged the boreholes, visually examined the recovered samples, and transported them to Thurber's laboratory for further examination and testing.

Groundwater conditions in the open boreholes were observed throughout the drilling operations. In Borehole CC11-02, a standpipe piezometer consisting of 19 mm PVC pipe with screen was installed and enclosed in filter sand to permit longer term groundwater level monitoring. Boreholes without piezometer installations were grouted with bentonite upon completion. The borehole decommissioning details are shown in Table 3.1.

Table 3.1 – Borehole Decommissioning Details

Borehole	Piezometer Tip Depth/ Elevation (m)	Completion Details
CC11-01	None installed	Borehole backfilled with holeplug to 0.1 m, then cold patch asphalt to surface.
CC11-02	12.2/210.3	Holeplug from 31.1 to 12.2 m, sand filter from 12.2 to 10.4 m, holeplug from 10.4 to 9.1 m, auger cuttings from 9.1 to 0.1 m, then cold patch asphalt to surface.
CC11-03	None installed	Borehole backfilled with holeplug to 0.1 m, then cold patch asphalt 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 grain size distribution analyses (sieve and hydrometer) and Atterberg Limits testing where appropriate. The results of this testing program are shown on the Record of Borehole sheets in Appendix A and on the figures contained in Appendix B.

5 DESCRIPTION OF SUBSURFACE CONDITIONS

Reference is made to the Record of Borehole sheets in Appendix A for details of the encountered soil stratigraphy. A stratigraphic profile is presented on the Borehole Locations and Soil Strata Drawing in Appendix E, for illustrative purposes. Overall descriptions of the stratigraphy are given in the following paragraphs. However, the factual data presented in the Record of Borehole Sheets governs any interpretation of the site conditions. It must be recognized that soil conditions may vary between and beyond borehole locations.

The soil stratigraphy encountered at the borehole locations typically consists of an asphalt layer overlying sand fill and clayey silt fill (embankment fill), underlain by native silt to the full exploration depth.

More detailed descriptions of the individual strata are presented below.

5.1 Asphalt

A 150 mm thick layer of asphalt was encountered in each borehole drilled on the travelled lanes of Highway 11.

5.2 Sand Fill

The asphalt was underlain by fill consisting of sand, some gravel to gravelly, with occasional cobbles. The lower boundary of the sand fill was encountered at depths of 4.1 to 4.9 m (Elev. 217.6 to 218.5 m).

SPT 'N' values in the sand fill typically decreased with depth, ranging from 105 blows/0.1 m penetration (probably frozen) to 4 blows/0.3 m (loose). Typically the 'N' values were in the order of 11 to 22 blows/0.3m, indicating a compact condition. Moisture contents varied from 2 to 8%.

Grain size distribution curves for three samples of the sand fill are presented on the Record of Borehole sheets and on Figure B1 of Appendix B. The results of the laboratory tests are summarized as follows:

Gravel %	19 to 32
Sand %	59 to 73
Silt & Clay %	8 to 11

5.3 Clayey Silt Fill

Grey clayey silt fill was encountered below the sand fill in each borehole. The thickness of the silt fill was 3.8 to 5.9 m. The depth to the base of the clayey silt fill ranged from 8.7 to 9.9 m (Elev. 212.6 to 213.9 m), and a further 0.9 m of silt fill (base at Elev. 211.7 m) was encountered in Borehole CC11-03.

The consistency of the cohesive fill was firm to stiff in Borehole CC11-01, based on SPT 'N' values ranging from 4 to 13 blows/0.3 m. In Boreholes CC11-02 and CC11-03, the clayey silt fill was very stiff to hard, based on 'N' values of 25 to 31 blows/0.3 m. The moisture content typically varied from 18 to 25%, with one value of 39% measured in Borehole CC11-01.

Grain size distribution curves for two silt fill samples are presented on the Record of Borehole sheets and on Figure B2 of Appendix B. The results are summarized as follows:

Gravel %	0
Sand %	2 to 3
Silt %	71 to 74
Clay %	23 to 27

5.4 Silt

A deep deposit of native grey silt with some clay was contacted below the embankment fill at depths of 8.7 to 10.8 m (Elev. 211.7 to 213.9 m) in all boreholes. The boreholes were terminated within the silt at depths of 28.0 to 31.1 m (Elev. 191.4 to 194.6 m), indicating a strata thickness of at least 17.2 to 22.4 m.

SPT 'N' values in the silt ranged from 5 to 19 blows/0.3 m, indicating a loose to compact relative density. The moisture contents typically varied from 19 to 28%, with localized values of 35 to 42%.

Grain size distribution curves for the silt are presented on the Record of Borehole sheets and on Figure B3 of Appendix B. The results of the laboratory tests are summarized as follows:

Gravel %	0
Sand %	0
Silt %	78 to 84
Clay %	16 to 22

A dynamic cone penetration test conducted near Borehole CC11-02 indicated relatively consistent blow counts in the native silt, typically in the order of 60 to 70 blows/0.3 m, increasing to over 80 blows/0.3 m near the test termination depth of 22.5 m. In Boreholes CC11-04 and CC11-05, the DCPT blow counts typically/gradually increased from less than 10 blows/0.3 m near the ground surface to around 80 blows/0.3 m at about 13 m depth.

These tests were terminated at depths of 14.9 and 15.8 m after counts of 100 to 126 blows/0.3 m were obtained.

5.5 Silty Clay

The native deposits graded to silty clay from 10.7 to 12.2 m depth in Borehole CC11-01 and from 13.9 to 16.8 m depth in Borehole CC11-02. The thickness of the silty clay zone was 1.5 and 2.9 m.

SPT 'N' values of 3 and 7 blows/0.3 m were obtained in the silty clay, indicating a soft to firm consistency. The undrained shear strength determined by an in situ vane test conducted in Borehole CC11-02 was 30 kPa (firm). Moisture contents of 21 and 22% were measured.

The results of a grain size distribution analysis conducted on a sample of the silty clay are presented on the Record of Borehole sheets and on Figure B4 of Appendix B. The results are summarized as follows:

Gravel %	0
Sand %	0
Silt %	67
Clay %	33

5.6 Water Levels

Water was added into the drill casing to counterbalance hydraulic pressures during drilling and therefore natural groundwater levels were not measured during drilling. A standpipe piezometer was installed in Borehole CC11-02 to monitor water levels after completion of drilling. The water level measured in the piezometer on April 30, 2011 was at 8.5 m depth (Elev. 214.0 m).

The water level in the Cash Creek tributary in February 2011 was at Elev. 212.7 m (from preliminary General Arrangement drawing).

The above values are short-term readings and fluctuations of the groundwater level are to be expected subject to seasonal conditions and the water level in the creek. In particular, the groundwater level may be at a higher elevation after the spring snowmelt or after periods of heavy rainfall.

6 MISCELLANEOUS

The borehole locations were established in the field by Thurber Engineering. The coordinates and ground surface elevations at the boreholes were subsequently determined by MMM Group Limited survey personnel.

Thurber obtained utility clearances for the borehole locations prior to drilling.

Eastern Ontario Diamond Drilling Ltd. supplied truck-mounted drilling equipment and conducted the drilling, sampling and in-situ testing operations for the boreholes drilled on the highway. OGS Inc. supplied portable equipment to advance the DCPT tests at the base of the embankment slope.

The field program was supervised on a full time basis by Ms. Eckie Siu and Mr. Ryan Kromer of Thurber Engineering Ltd. Overall supervision of the field program was provided by Mr. Alastair E. Gorman, P.Eng. and Mr. Tony Harte, M.Sc.

Interpretation of the data and preparation of the report was carried out by 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 in the factual report and presents geotechnical recommendations for design of a new culvert to replace the existing culvert at Cash Creek.

The existing culvert is a rigid frame concrete culvert with a length of 46.1 m, width of 2.9 m and height of approximately 1.5 m. The proposed culvert (as shown on the Preliminary General Arrangement dated April/11) consists of two parallel sheet pile walls with a precast concrete panel cap. The new structure will have a span of 10.0 m, a height of about 7.5 m, and a length of 47 m of which 24 m will be capped.

The approximate invert level (original ground) will be near Elev. 212.5 m and the concrete cap will be at Elev. 220.0 m. Existing and finished road grades over the culvert will be at Elev. 222.57 m, resulting in a maximum embankment height of about 10 m.

The proposed culvert design and installation methods have been established through discussions between the structural designer and MTO's Northwest Region Office, taking into consideration alternative culvert types, environmental restrictions, roadway protection requirements, and construction material availability. Alternative options such as trenchless methods or culvert lining were excluded from further consideration.

The discussions and recommendations presented in this report are based on the factual data obtained during the course of the investigation. The plans and profiles used for preparation of this report were provided by McCormick Rankin Corporation.

8 STRUCTURE FOUNDATIONS

In general, the site is underlain by a deep deposit of loose to compact silt extending to the full exploration depths of 28.0 to 31.1 m. The existing embankment consists of 4.1 to 4.9 m of sand fill overlying 3.8 to 5.9 m of clayey silt fill. The groundwater level at the site was measured at Elev. 214.0 m and the water level in the creek was at Elev. 212.7 m in February 2011.

Geotechnical recommendations for design of the proposed sheet pile wall culvert are presented in the following sections. Foundation alternatives together with the corresponding geotechnical design parameters are also presented in the event that the culvert design concept changes.

A comparison of the technical advantages and disadvantages of alternative foundation schemes (driven steel H-piles, spread footings on native soil, and caissons/drilled shafts) is presented in Appendix C. A foundation scheme preferred from a foundations perspective is recommended.

8.1 Steel Sheet Pile Walls

Driven steel sheet piles will develop resistance to vertical loads primarily through frictional resistance along the sides of the piles within the native loose to compact silt.

The factored Geotechnical Resistances at ULS (per metre width) and Geotechnical Resistances at SLS recommended for two sheet pile sections driven to depths of 5, 10 and 15 m into the native silt are as follows:

Table 8.1 – Recommended Axial Resistances of Steel Sheet Piles

Sheet Pile Section	Embedment Length in Native Silt (m)	Approximate Pile Toe Elevation (m)	Factored ULS Resistance per meter width (kN)	SLS Resistance (kN)
EZ-88	5	207.5	275	225
	10	202.5	650	450
	15	197.5	1,100	750
XZ-100	5	207.5	275	225
	10	202.5	700	475
	15	197.5	1,200	800
JZ-127	5	207.5	300	250
	10	202.5	750	500
	15	197.5	1,300	850

The SLS values are based on a vertical pile settlement of 25 mm at the base of the embankment fill. Elastic compression of the pile above this level will be in addition to this settlement.

Pile installation should be in accordance with OPSS 903.

Sheet piles should be driven to the specified elevation noted in Table 8.1. The appropriate pile driving note is “Piles to be driven to El. ____”. An additional note should be included

to indicate that installation of permanent sheet pile walls by vibratory equipment is not permitted.

The lateral resistance of sheet piles may be computed using the lateral earth pressure distribution and parameters presented in Section 9.

Design of the permanent sheet pile walls must consider environmental conditions such as road salts or fluctuating water levels that may cause long-term corrosion and reduce the service life of the structure.

8.2 Steel H-Pile Foundations

Driven steel H-piles will develop resistance to vertical loads primarily through frictional resistance along the shafts of the piles within the native loose to compact silt.

The factored Geotechnical Resistances at ULS (per pile) and Geotechnical Resistance at SLS (25 mm settlement) recommended for an HP 310x110 H-pile section driven to various depths into the native silt are as follows:

Table 8.2 – Recommended Axial Resistances for Steel H-Piles

Embedment Length in Native Silt (m)	Approximate Pile Tip Elevation (m)	Factored ULS Resistance per pile (kN)	SLS Resistance (kN)
10	202.5	450	400
15	197.5	750	575
20	192.5	1,075	700
25	187.5	1,450	780

The SLS values are based on a vertical pile settlement of 25 mm at the base of the embankment fill. Elastic compression of the pile above this level will be in addition to this settlement.

The structural resistance of the pile must be checked by the structural designer.

Downdrag on the piles is not considered to be an issue at this site.

Pile installation should be in accordance with OPSS 903.

8.2.1 Pile Lateral Resistance

The geotechnical lateral resistance acting on an H-pile in silt may be calculated using a value for the coefficient of horizontal subgrade reaction (k_s) and ultimate lateral resistance (p_{ult}) as follows:

$$\begin{aligned}
 k_s &= n_h z / D && (\text{kN/m}^3) \\
 p_{ult} &= 3 \gamma z K_p && (\text{kPa}) \\
 \text{where } z &= \text{depth of embedment of pile in metres} \\
 D &= \text{pile width in metres} \\
 n_h &= \text{coefficient of horizontal subgrade reaction} \\
 &= 4,000 \text{ kN/m}^3 \text{ in loose to compact silt} \\
 \gamma &= \text{unit weight} \\
 &= 11 \text{ kN/m}^3 \text{ (buoyant unit weight below water table)} \\
 K_p &= \text{passive earth pressure coefficient} \\
 &= 3.0 \text{ for loose to compact silt}
 \end{aligned}$$

The ultimate lateral resistance of sheet piles may be computed using the lateral earth pressure parameters presented in Section 9 with $p_{ult} = K_p \gamma z$. The coefficient of horizontal subgrade reaction may be computed using the equation above and a pile width D of unity.

The above equations and recommended parameters may be used to analyze the interaction between a pile and the surrounding soil. The lateral pressures obtained from the analysis must not exceed the ultimate lateral resistance.

The spring constant, K_s , for analysis may be obtained by the expression, $K_s = k_s \times L \times D$ (kN/m), where k_s is the coefficient of horizontal subgrade reaction (kN/m³), D is the pile width (m) and L is the length (m) of the pile segment or element used in the analysis. The ultimate lateral resistance, P_{ult} , may be obtained from the expression, $P_{ult} = p_{ult} \times L \times D$. This represents the ultimate load at which the pile fails and will not support any additional load at greater displacements. It is recommended, however, that the total lateral resistance assumed in one pile be limited to no more than 150 kN at ULS and 50 kN at SLS.

The modulus of subgrade reaction may have to be reduced, based on the pile spacing. The reduction factors to be used for a pile group oriented perpendicular or parallel to the direction of loading are provided in Table 8.3. Intermediate values may be obtained by linear interpolation.

Table 8.3 – Subgrade Reaction Reduction Factors for Pile Spacing

Condition	Pile Spacing, Centre to Centre*	Reduction Factor
Pile group oriented <i>perpendicular</i> to direction of loading	4D	1.0
	1D	0.5
Pile group oriented <i>parallel</i> to direction of loading	8D	1.0
	6D	0.7
	4D	0.4
	3D	0.25

* where D is the width of pile

Alternatively, horizontal loads may be resisted by means of battered piles.

8.3 Spread Footings on Native Soil

Spread footings for an open frame culvert should be founded on loose to compact native silt below the level of all fill, topsoil and streambed deposits.

The anticipated founding level, assuming 2.3 m of frost cover over the footing base, is elevation 210.2 m. Footings for an open footing culvert founded on the loose to compact silt at this level may be designed using the following resistance values:

Assumed Footing Width (m)	=	<u>1.2</u>	<u>2.4</u>
Factored Geotechnical Resistance at ULS (kPa)	=	140	170
Geotechnical Resistance at SLS (kPa)	=	125	75

The resistance values provided 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 Clause 6.7.3 and Clause 6.7.4.

The geotechnical SLS resistance values given above are based on an estimated total settlement not exceeding 25 mm. This settlement is expected to be substantially complete by the end of construction.

The lateral resistance of the footings may be computed using an unfactored friction coefficient of 0.35 on loose to compact silt. This is an “ultimate” value and requires a degree of sliding movement to occur to fully mobilize the resistance.

All founding surfaces should be protected from disturbance during construction by placement of a 75 mm working slab on the prepared bearing surface as soon as practical following inspection and approval.

Considering the very low resistance values available, use of spread footings is not recommended at this site.

8.4 Caissons

Caisson bearing material was not encountered within the exploration depths of 28.0 to 31.1 m. Further, caisson construction in the silt below the groundwater level at this site would require specialized construction techniques such as the use of drilling mud and a caisson liner to support the sidewalls and maintain base stability. In view of these factors, the use of caissons is not recommended and this alternative has not been developed further.

8.5 Recommended Foundation

A culvert consisting of a precast concrete cap supported on driven steel sheet piles deriving axial resistance through skin friction in the native silt has been selected as the preferred

option for this site based on non-geotechnical considerations. Recommendations for design of this type of culvert have been provided. From a geotechnical perspective and based on the subsurface conditions, alternative culvert types such as a smaller precast concrete box installed using a braced excavation/cofferdam or a pipe culvert installed using trenchless techniques are both feasible options but have not been developed further.

8.6 Frost Cover

The depth of frost penetration at this site is 2.3 m. The base of all footings and pile caps, if employed, must be provided with a minimum of 2.3 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 Granular A or Granular B Type II specifications. It is recommended that a minimum 2 m width of granular material be placed adjacent to the proposed sheet pile walls to provide drainage and protection against frost action in the highly frost-susceptible silt soils at the site. The granular material should extend 2.3 m (frost depth) below the exposed face of the sheet pile wall, or to the low water level in the creek if above this depth. The extent of the granular material could be reduced by the use of insulation to protect the silt from frost action. If conventional culvert design is planned, the granular backfill should extend to the limits shown in OPSD 803.010.

Heavy compaction equipment should not be used adjacent to the walls and roof of the culvert. Compaction should be carried out in accordance with OPSS 501. Backfill for a conventional culvert 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.

In general, earth pressures acting on the culvert walls may be assumed to impose a triangular distribution governed by the characteristics of the backfill. For a fully drained condition, the pressures should be computed in accordance with the CHBDC but generally are given by the expression:

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

where: p = horizontal pressure on the wall at depth h (kPa)
 K = earth pressure coefficient (see Tables 9.1 and 9.2)
 γ = bulk unit weight of retained soil (see Tables 9.1 and 9.2)
 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 are dependent on the material used as backfill and the inclination of the ground surface behind the wall. Recommended unfactored values for a level ground surface and sloping ground at 2H:1V are shown in Tables 9.1 and 9.2, respectively.



Table 9.1 – Earth Pressure Coefficients (K) for Horizontal Ground Surface

Condition	Earth Pressure Coefficient (K)			
	OPSS Granular A or OPSS Granular B Type II $\phi = 35^\circ, \gamma = 22.8 \text{ kN/m}^3$	Existing Sand Fill or OPSS Granular B Type I $\phi = 32^\circ, \gamma = 21.2 \text{ kN/m}^3$	Clayey Silt Fill $\phi = 29^\circ$ $\gamma = 20 \text{ kN/m}^3$	Native Silt $\phi = 30^\circ$ $\gamma = 21.2 \text{ kN/m}^3$
Active (Unrestrained Wall)	0.27	0.31	0.35	0.33
At rest (Restrained Wall)	0.43	0.47	0.51	0.50
Passive (Movement Towards Soil Mass)	3.7	3.3	2.9	3.0

Table 9.2 – Earth Pressure Coefficients (K) for Sloping Ground Surface (2H:1V)

Condition	Earth Pressure Coefficient (K)			
	OPSS Granular A or OPSS Granular B Type II $\phi = 35^\circ, \gamma = 22.8 \text{ kN/m}^3$	Existing Sand Fill or OPSS Granular B Type I $\phi = 32^\circ, \gamma = 21.2 \text{ kN/m}^3$	Clayey Silt Fill $\phi = 29^\circ$ $\gamma = 20 \text{ kN/m}^3$	Native Silt $\phi = 30^\circ$ $\gamma = 21.2 \text{ kN/m}^3$
Active (Unrestrained Wall)	0.38	0.46	0.59	0.54
At rest (Restrained Wall)	0.43	0.47	0.51	0.50
Passive (Movement Towards Soil Mass)	2.1	1.7	1.4	1.5

The at-rest coefficients should be employed for closed box culvert walls. Active pressures shall be used for any wingwalls or unrestrained walls.

The parameters in the table 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.

Braced flexible sheeting typically undergoes insufficient movement to establish a full active condition and a triangular pressure distribution may not apply. For the case of a braced flexible wall, the lateral earth pressures should be computed using a trapezoidal distribution as shown on Figure C1, Appendix C.

For a temporary slope behind the wall inclined steeper than 2H:1V, the active pressure coefficients for a sloping surface shown in the table may be applied and the additional soil above a line inclined at 2H:1V should be treated as a surcharge load.

For the at-rest condition, all soil above a horizontal surface behind the wall should be treated as a surcharge load.

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.

The design of the culvert must incorporate measures such as weepholes or subdrains to permit drainage of the culvert backfill, or alternatively the culvert walls should be designed to withstand the potential build-up of hydrostatic pressures behind the walls.

10 EROSION CONTROL

Erosion protection should be provided at the culvert inlet area. Design of the erosion protection measures must consider hydrologic and hydraulic concerns and should be carried out by specialists experienced in this field.

Typically, rip-rap should be provided over all surfaces with which stream flow is likely to be in contact. Treatment should be in accordance with OPSD 810.010. A geotextile should be placed over the exposed subgrade prior to placement of the rip-rap treatment, in accordance with OPSS 511. A vegetation cover should be established on all other exposed earth surfaces to protect against surficial erosion, in general accordance with OPSS 804.

11 EXCAVATION AND GROUNDWATER CONTROL

Culvert installation will be carried out in stages to maintain one lane of traffic at all times. For installation of the proposed steel sheet pile wall culvert, the following construction sequence is envisioned:

1. Install roadway protection parallel to centreline of highway, maintaining sufficient width for one way traffic.
2. Excavate to top of sheet pile level and install steel sheet piling along both sides of the culvert.
3. Place precast concrete panels to form top cap of culvert.
4. Excavate simultaneously outside of sheet piles on both sides of culvert and backfill both sides simultaneously with granular backfill. Below Elevation 214 (groundwater level), excavate and backfill in short sections.
5. Complete embankment construction up to pavement subgrade.
6. Reposition roadway protection (if necessary) and repeat procedures for second half of culvert installation.
7. Excavate soil from inside of the sheet pile culvert and remove existing culvert.

All excavation must be carried out in accordance with the Occupational Health and Safety Act (OHSA). For the purposes of the OHSA, the sand fill and clayey silt fill forming the existing embankment may be classified as Type 3 soils. The native silt above the water table may also be classed as Type 3 soils. This classification is based on the lack of cohesion in the soils. The silt below the water table is a Type 4 soil.

Roadway protection must be supplied in accordance with OPSS 539 and designed for Performance Level 2. The protection systems should be designed by a licensed Professional Engineer experienced in design of shoring with consideration of adjacent traffic loads and any sloping retained surfaces. Based on available subsurface information, a shoring system consisting of steel sheet piles or H-piles with timber lagging may be considered.

The groundwater level at the site is expected to be at or above the water level measured in the piezometer (Elev. 214.0 m in May 2011). Based on the preliminary culvert design, excavation below the groundwater level to construct the new sheet pile culvert will not be required. However, excavation below the creek level along with creek diversion may be required to remove the existing culvert foundations, or if an alternate culvert design is selected.

Excavation below the groundwater level without prior dewatering is not recommended since the inflow of groundwater will cause boiling and sloughing of the soil below the water table making it difficult to maintain a dry, sound base on which to work. Prior to excavation below the natural groundwater level, the groundwater must be depressed to a level at least 0.6 m below the deepest excavation level, sufficient to maintain a stable base and prevent soil disturbance by construction traffic. Alternatively, excavation in short segments (2 to 3 m) followed by immediate backfilling with granular material may be considered for shallow excavations below the groundwater level.

The Contractor must be prepared to control the groundwater and surface water to permit construction in the dry. The Contract Documents should contain a NSSP alerting the Contractor to the risks associated with excavation of cohesionless soils submerged below the groundwater level without prior dewatering. Suggested wording is included in Appendix D.

The design of the 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. While the responsibility for dewatering remains with the Contractor, suitable systems that might be employed include pumping from filtered sumps for penetration of no more than 0.5 m below the groundwater level and the use of vacuum wellpoints for deeper penetration below the groundwater level.

The Contractor should also be prepared to pump from sumps to remove any remaining seepage water or surface water collecting in an excavation. Placement of concrete (if required) must be done in the dry. Unwatering must remain operational and effective until the culvert is installed and backfilled.

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

12 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 0.02

The soil profile type at this site has been classified as Type IV based on a silt strata thickness of at least 17.2 to 22.4 m. Therefore, according to Table 4.4.6.1 of the CHBDC, a Site Coefficient “S” (ground motion amplification factor) of 2.0 should be used in seismic design.

In accordance with Clause 4.6.4 of the CHBDC, retaining structures should be designed using active (K_{AE}) and passive (K_{PE}) earth pressure coefficients that incorporate the effects of earthquake loading. The coefficients of horizontal earth pressure for seismic loading presented in Table 12.1 may be used:

Table 12.1 – Earth Pressure Coefficients for Earthquake Loading

Condition	Earth Pressure Coefficient (K)			
	OPSS Granular A or OPSS Granular B Type II $\phi = 35^\circ, \gamma = 22.8 \text{ kN/m}^3$	Existing Sand Fill or OPSS Granular B Type I $\phi = 32^\circ, \gamma = 21.2 \text{ kN/m}^3$	Clayey Silt Fill $\phi = 29^\circ$ $\gamma = 20 \text{ kN/m}^3$	Native Silt $\phi = 30^\circ$ $\gamma = 21.2 \text{ kN/m}^3$
Active (K_{AE})*	0.28	0.32	0.36	0.34
Passive (K_{PE})	3.7	3.2	0.54	0.53
At Rest (K_{OE})**	0.45	0.50	2.9	3.0

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

** After Woods

The site overlies loose to compact cohesionless deposits and a high water table is present at this site. A cursory review of the subsurface conditions indicates that a potential for liquefaction exists under current conditions at this site. Localized liquefaction during a seismic event may result in local toe failure or minor embankment settlement, but this is expected to be readily repairable.

13 CONSTRUCTION CONCERNS

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

- Buried obstructions in the existing embankment fill that may be encountered during excavation or interfere with driving of piles.
- Excavation below the water level, if required, will require lowering of the groundwater level below the excavation base to maintain a reasonably dry excavation. Alternatively, excavation in short segments followed by immediate backfilling with granular material may be considered for shallow excavations below the groundwater level.
- Roadway protection must be provided to maintain traffic during construction. Temporary shoring systems should be properly designed by a Professional Engineer experienced in such designs.

The successful performance of the culvert will depend largely upon good workmanship and quality control during construction. Pile driving supervision, subgrade examination and field density testing should be carried out by qualified geotechnical personnel during construction to confirm that foundation recommendations are correctly implemented and material specifications are met.

14 CLOSURE

Engineering analysis and preparation of the foundation design report were carried out by 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.

Murray R. Anderson, P.Eng., M.Eng.
Senior Foundations Engineer



P.K. Chatterji, P.Eng., Ph.D.
Review Principal



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
 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			

RECORD OF BOREHOLE No CC11-01

1 OF 3

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 495.7 E 215 049.0 ORIGINATED BY ES
 HWY 11 BOREHOLE TYPE Hollow Stem Augers/Casing COMPILED BY AN
 DATUM Geodetic DATE 2011.01.14 - 2011.01.16 CHECKED BY TJH

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	
222.6												
0.0	ASPHALT: (150mm)											
0.2	SAND, some gravel, occasional cobbles Very Dense to Compact Brown Damp (FILL)		1	SS	105/ 0.100		222					
			2	SS	39							
			3	SS	22		221					
			4	SS	11		220					19 73 8 (SI+CL)
			5	SS	4		219					
218.5												
4.1	Clayey SILT, trace sand, occasional wood fibres Firm to Stiff Grey (FILL)		6	SS	13		218					
							217					
			7	SS	4		216					
							215					
			8	SS	9							
213.9							214					
8.7	SILT, some clay Loose Grey Moist		9	SS	10		213					0 0 84 16

Continued Next Page

+³, ×³: Numbers refer to
Sensitivity

20
15
10

(%) STRAIN AT FAILURE

RECORD OF BOREHOLE No CC11-01

2 OF 3

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 495.7 E 215 049.0 ORIGINATED BY ES
 HWY 11 BOREHOLE TYPE Hollow Stem Augers/Casing COMPILED BY AN
 DATUM Geodetic DATE 2011.01.14 - 2011.01.16 CHECKED BY TJH

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)				
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)				GR	SA	SI	CL	
	Continued From Previous Page							20	40	60	80	100	w _p	w	w _L						
211.9	SILT, some clay Loose Grey Moist						212														
10.7	Silly CLAY Soft Grey		10	SS	3																
							211														
210.4																					
12.2	SILT, some clay Loose to Compact Grey Wet		11	SS	6		210														
							209														
			12	SS	6																
							208														
			13	SS	9		207														
							206														
			14	SS	9																
							205														
			15	SS	11		204														
							203														

Continued Next Page

+ ³ . X ³ : Numbers refer to
Sensitivity

20
15
10
(%) STRAIN AT FAILURE

RECORD OF BOREHOLE No CC11-01

3 OF 3

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 495.7 E 215 049.0 ORIGINATED BY ES
HWY 11 BOREHOLE TYPE Hollow Stem Augers/Casing COMPILED BY AN
DATUM Geodetic DATE 2011.01.14 - 2011.01.16 CHECKED BY TJH

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT W _P	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa								
						○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE				WATER CONTENT (%)						
						20	40	60	80	100	20	40	60			
	Continued From Previous Page															
	SILT, some clay Loose to Compact Grey Wet		16	SS	9											
			17	SS	14											
			18	SS	15											
			19	SS	19											
194.6																
28.0	END OF BOREHOLE AT 28.0m. BOREHOLE BACKFILLED WITH HOLEPLUG TO 0.1m, THEN ASPHALT TO SURFACE.															

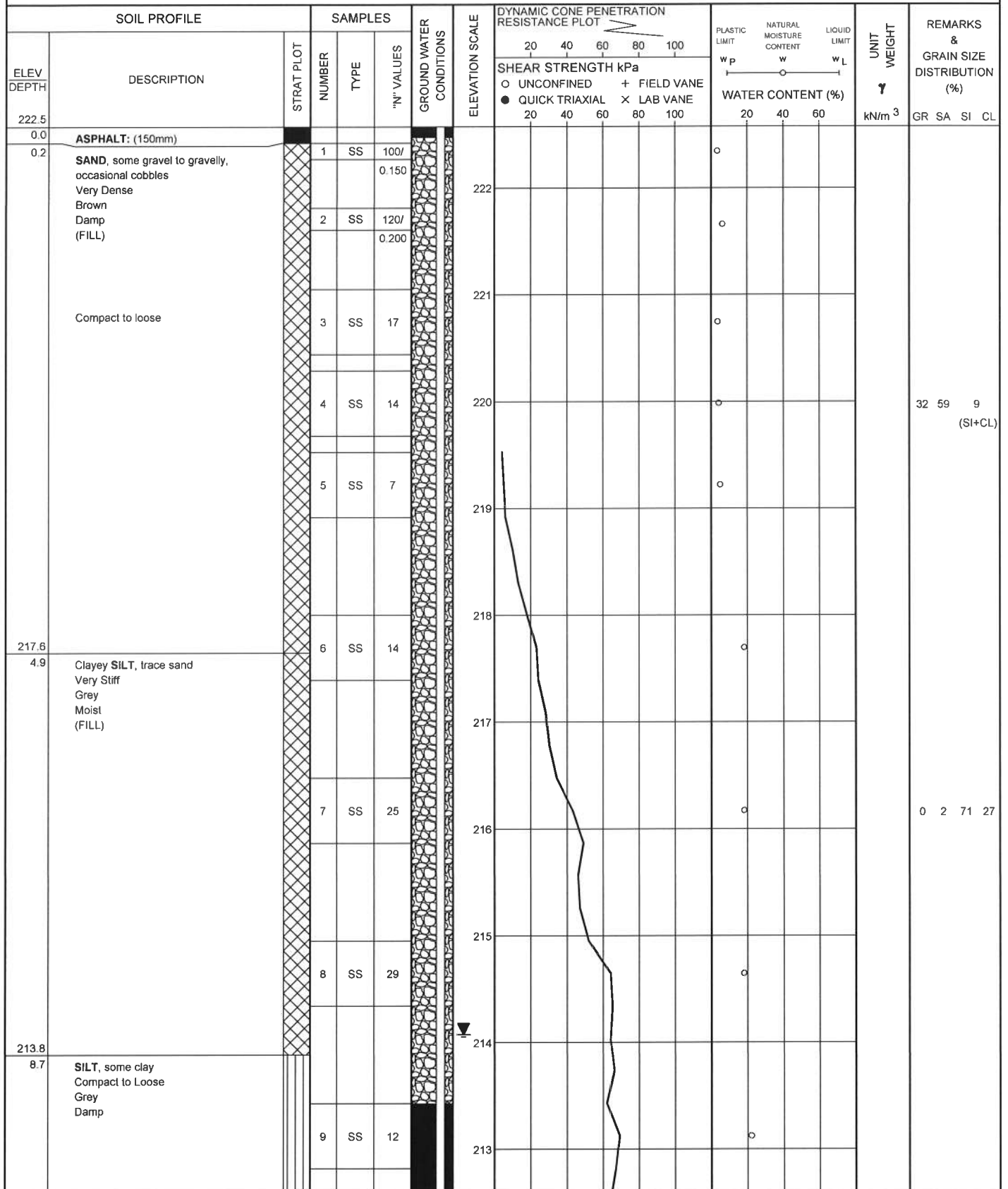
ONTMT4S 1197.GPJ 5/6/11

RECORD OF BOREHOLE No CC11-02

1 OF 4

METRIC

W.P. 6048-08-00 LOCATION Cash Creek Culvert N 5 448 490 4 E 215 051 4 ORIGINATED BY ES
HWY 11 BOREHOLE TYPE Hollow Stem Augers/Casing COMPILED BY AN
DATUM Geodetic DATE 2011.01.12 - 2011.01.13 CHECKED BY TJH



Continued Next Page

+ 3. X 3. Numbers refer to Sensitivity 20 15 10 (%) STRAIN AT FAILURE

RECORD OF BOREHOLE No CC11-02

2 OF 4

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 490.4 E 215 051.4 ORIGINATED BY ES
 HWY 11 BOREHOLE TYPE Hollow Stem Augers/Casing COMPILED BY AN
 DATUM Geodetic DATE 2011.01.12 - 2011.01.13 CHECKED BY TJH

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT w _P	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	*N VALUES			SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE						
	Continued From Previous Page							20 40 60 80 100						
	SILT, some clay Compact to Loose Grey Moist		10	SS	13			212						
								211						
			11	SS	7			210						
208.6								209						
13.9	Silty CLAY, occasional silt seams Firm Grey		12	SS	7			208						0 0 67 33
								207						
205.8								206						
16.8	SILT, some clay Compact Grey Wet		13	SS	13			205						
								204						
			14	SS	11			203						

Continued Next Page

+³ x³: Numbers refer to
Sensitivity 20
15 10 5 0 (%) STRAIN AT FAILURE

RECORD OF BOREHOLE No CC11-02

3 OF 4

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 490.4 E 215 051.4 ORIGINATED BY ES
 HWY 11 BOREHOLE TYPE Hollow Stem Augers/Casing COMPILED BY AN
 DATUM Geodetic DATE 2011.01.12 - 2011.01.13 CHECKED BY TJH

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	20 40 60 80 100					
	Continued From Previous Page		15	SS	12		202							
			16	SS	13		201							0 0 81 19
			17	SS	11		198							
			18	SS	12		195							
	Occasional clay seams						194							
							193							

Continued Next Page

+³, ×³: Numbers refer to Sensitivity 20 15 10 5 0 (%) STRAIN AT FAILURE

RECORD OF BOREHOLE No CC11-02

4 OF 4

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 490.4 E 215 051.4 ORIGINATED BY ES
HWY 11 BOREHOLE TYPE Hollow Stem Augers/Casing COMPILED BY AN
DATUM Geodetic DATE 2011.01.12 - 2011.01.13 CHECKED BY TJH

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT CONTENT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	SHEAR STRENGTH kPa					WATER CONTENT (%)			
							20	40	60	80	100	W _p	W	W _L		
	Continued From Previous Page															
191.4	SILT, some clay Compact Grey Wet		19	SS	14	192										
31.1	END OF BOREHOLE AT 31.1m. Piezometer installation consists of 19mm diameter Schedule 40 PVC pipe with a 1.52m slotted screen. WATER LEVEL READINGS: DATE DEPTH (m) ELEV. (m) 2011.04.30 8.5 214.0															

RECORD OF BOREHOLE No CC11-03

1 OF 3

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 485.3 E 215 044.6 ORIGINATED BY ES
HWY 11 BOREHOLE TYPE Hollow Stem Augers/Casing COMPILED BY AN
DATUM Geodetic DATE 2011.01.18 - 2011.01.19 CHECKED BY TJH

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)				
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)				GR	SA	SI	CL	
								○ UNCONFINED	+ FIELD VANE	● QUICK TRIAXIAL	× LAB VANE		W _P	W	W _L						
222.5																					
0.0	ASPHALT: (150mm)																				
0.2	SAND, some gravel to gravelly, occasional cobbles Very Dense to Compact Brown Damp (FILL)		1	SS	100/ 0.125						○										
			2	SS	100/ 0.150						○										
			3	SS	20						○							29	60 11 (SI+CL)		
			4	SS	18						○										
			5	SS	20						○										
217.6			6	SS	20						○										
4.9	Clayey SILT, trace sand, occasional wood fibres Very Stiff to Hard Grey to Brownish Grey Damp (FILL)																				
			7	SS	26						○							0	3 73 24		
			8	SS	31						○										
			9	SS	31						○										
212.6																					

Continued Next Page

+³, x³: Numbers refer to
Sensitivity

20
15
10

(%) STRAIN AT FAILURE

RECORD OF BOREHOLE No CC11-03

2 OF 3

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 485.3 E 215 044.6 ORIGINATED BY ES
 HWY 11 BOREHOLE TYPE Hollow Stem Augers/Casing COMPILED BY AN
 DATUM Geodetic DATE 2011.01.18 - 2011.01.19 CHECKED BY TJH

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	*N* VALUES			SHEAR STRENGTH kPa								WATER CONTENT (%)		
								○ UNCONFINED	+	FIELD VANE								
								● QUICK TRIAXIAL	×	LAB VANE								
	Continued From Previous Page						20	40	60	80	100	20	40	60				
9.9	SILT, some sand, trace clay Dense Grey Damp (FILL)						212											
211.7							211											
10.8	SILT, some clay Compact to Loose Grey Moist		10	SS	16													
			11	SS	9		210											
			12	SS	7		209											
			13	SS	5		208											
			14	SS	10		207											
	Compact		15	SS	13		206											
							205											
							204											
							203											

Continued Next Page

+³, X³: Numbers refer to Sensitivity 20 15 10 5 0 (%) STRAIN AT FAILURE

RECORD OF BOREHOLE No CC11-03

3 OF 3

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 485.3 E 215 044.6 ORIGINATED BY ES
 HWY 11 BOREHOLE TYPE Hollow Stem Augers/Casing COMPILED BY AN
 DATUM Geodetic DATE 2011.01.18 - 2011.01.19 CHECKED BY TJH

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa										WATER CONTENT (%)		
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE												
	Continued From Previous Page		16	SS	15			20	40	60	80	100		20	40	60		0 0 81 19		
	SILT, some clay Compact Grey Moist						202													
			17	SS	13		201							○						
							200													
							199													
				18	SS	14		198							○					
							197													
						196														
194.4			19	SS	11		195								○					
28.0	END OF BOREHOLE AT 28.0m. BOREHOLE BACKFILLED WITH HOLEPLUG TO 0.1m, THEN ASPHALT TO SURFACE.																			

ONTMT4S 1197.GPJ 5/6/11

RECORD OF BOREHOLE No CC11-04

1 OF 2

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 499.3 E 215 026.0 ORIGINATED BY RK
 HWY 11 BOREHOLE TYPE Dynamic Cone Penetration Test COMPILED BY MFA
 DATUM Geodetic DATE 2011.02.19 - 2011.02.19 CHECKED BY TJH

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _P	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	SHEAR STRENGTH kPa					
212.3 0.0	Start of DCPT						20 40 60 80 100 ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE	20 40 60					
212													
211													
210													
209													
208													
207													
206													
205													
204													
203													

Continued Next Page

+³, ×³: Numbers refer to Sensitivity 20 15 10 5 0 (%) STRAIN AT FAILURE

RECORD OF BOREHOLE No CC11-04

2 OF 2

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 499.3 E 215 026.0 ORIGINATED BY RK
 HWY 11 BOREHOLE TYPE Dynamic Cone Penetration Test COMPILED BY MFA
 DATUM Geodetic DATE 2011.02.19 - 2011.02.19 CHECKED BY TJH

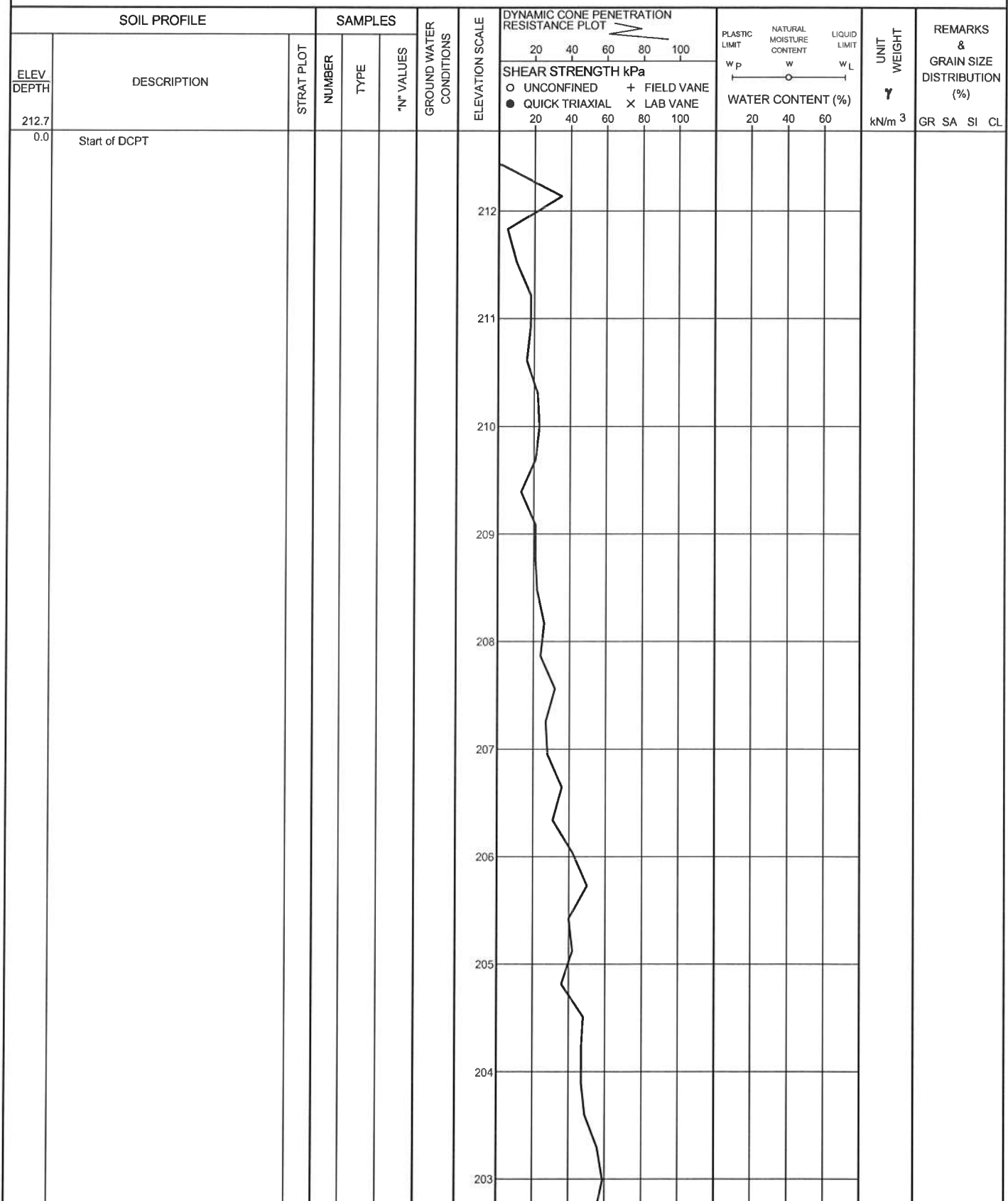
SOIL PROFILE				SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT	PLASTIC LIMIT	NATURAL MOISTURE CONTENT	LIQUID LIMIT	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES									
	Continued From Previous Page								<div><div>20406080100</div><div>SHEAR STRENGTH kPa</div><div>○ UNCONFINED + FIELD VANE</div><div>● QUICK TRIAXIAL x LAB VANE</div><div>20406080100</div></div>	<div><div>W_pW W_L</div><div>WATER CONTENT (%)</div><div>204060</div></div>				
197.4								202						
14.9	END OF DCPT AT 14.9m.							198						

+³, X³: Numbers refer to
Sensitivity

20
15
10
(%) STRAIN AT FAILURE

METRIC

W.P.	6932-10-00	LOCATION	Cash Creek Culvert N 5 448 474.1 E 215 070.7	ORIGINATED BY	RK
HWY	11	BOREHOLE TYPE	Dynamic Cone Penetration Test	COMPILED BY	MFA
DATUM	Geodetic	DATE	2011.02.19 - 2011.02.19	CHECKED BY	TJH



Continued Next Page

+³, ×³: Numbers refer to Sensitivity

RECORD OF BOREHOLE No CC11-05

2 OF 2

METRIC

W.P. 6932-10-00 LOCATION Cash Creek Culvert N 5 448 474.1 E 215 070.7 ORIGINATED BY RK
HWY 11 BOREHOLE TYPE Dynamic Cone Penetration Test COMPILED BY MFA
DATUM Geodetic DATE 2011.02.19 - 2011.02.19 CHECKED BY TJH

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		WATER CONTENT (%)			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL X LAB VANE	PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L			
	Continued From Previous Page												
196.8													
15.8	END OF DCPT AT 15.8m.												

+³, ×³: Numbers refer to
Sensitivity

20
15 5
10 (%) STRAIN AT FAILURE

Appendix B
Laboratory Test Results

FIGURE B1

U.S.S. Sieve size, meshes/inch

Size of openings, inches

PERCENT FINER THAN

GRAIN SIZE, mm

Grain Size (mm)	Percent Finer Than (Circles)	Percent Finer Than (Squares)	Percent Finer Than (Triangles)
0.075	10	8	7
0.15	15	14	12
0.3	25	22	20
0.6	47	33	30
1.2	65	44	42
2.5	75	57	56
5.0	82	69	70
7.5	87	80	87
10.0	95	89	95
25.0	100	100	100

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

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	CC11-01	2.59	220.03
■	CC11-02	2.59	219.93
▲	CC11-03	1.83	220.65

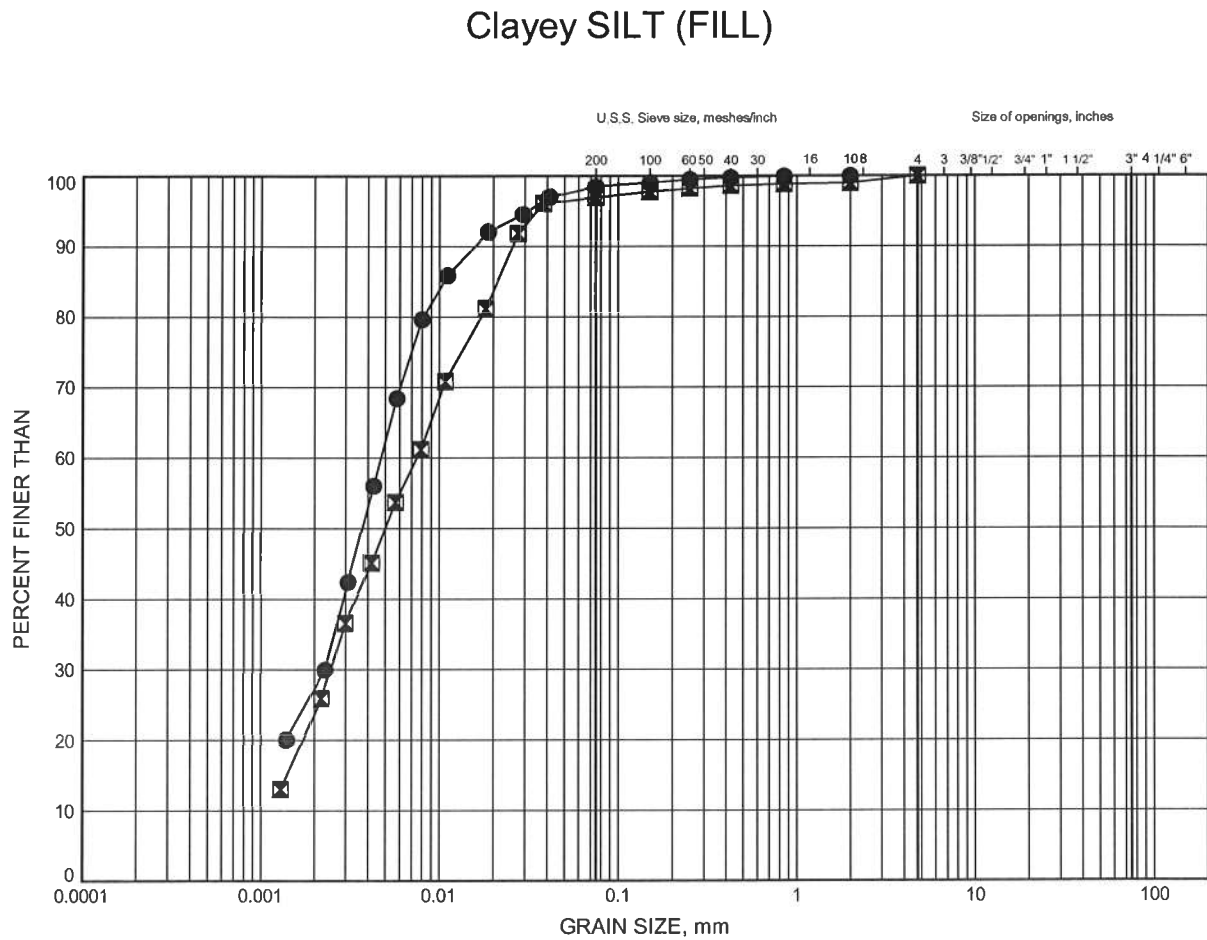


W.P.# 6932-10-00
Prepared By MFA
Checked By MRA

NWR 32 Rehabs

GRAIN SIZE DISTRIBUTION

FIGURE B2



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

LEGEND

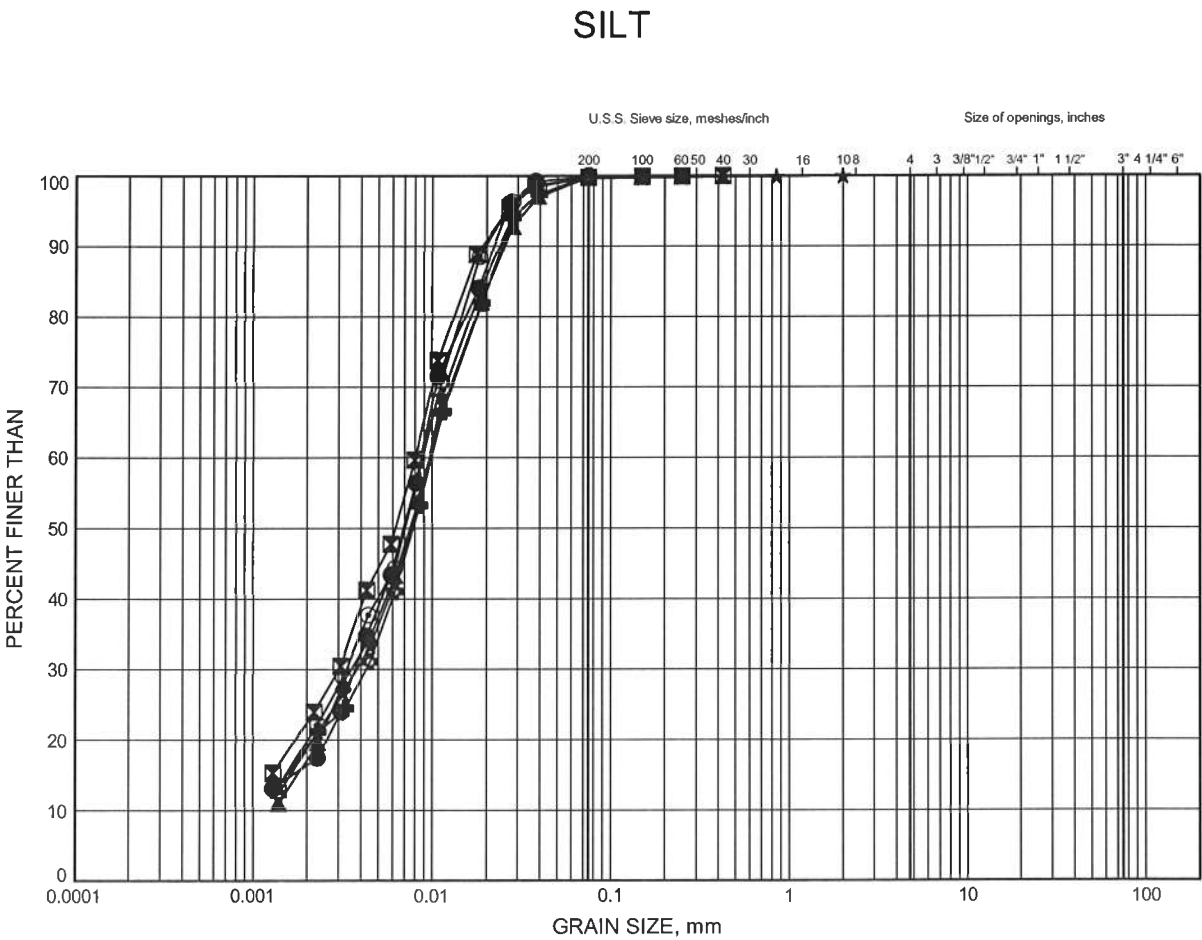
SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	CC11-02	6.40	216.12
⊠	CC11-03	6.40	216.08



NWR 32 Rehabs

GRAIN SIZE DISTRIBUTION

FIGURE B3



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

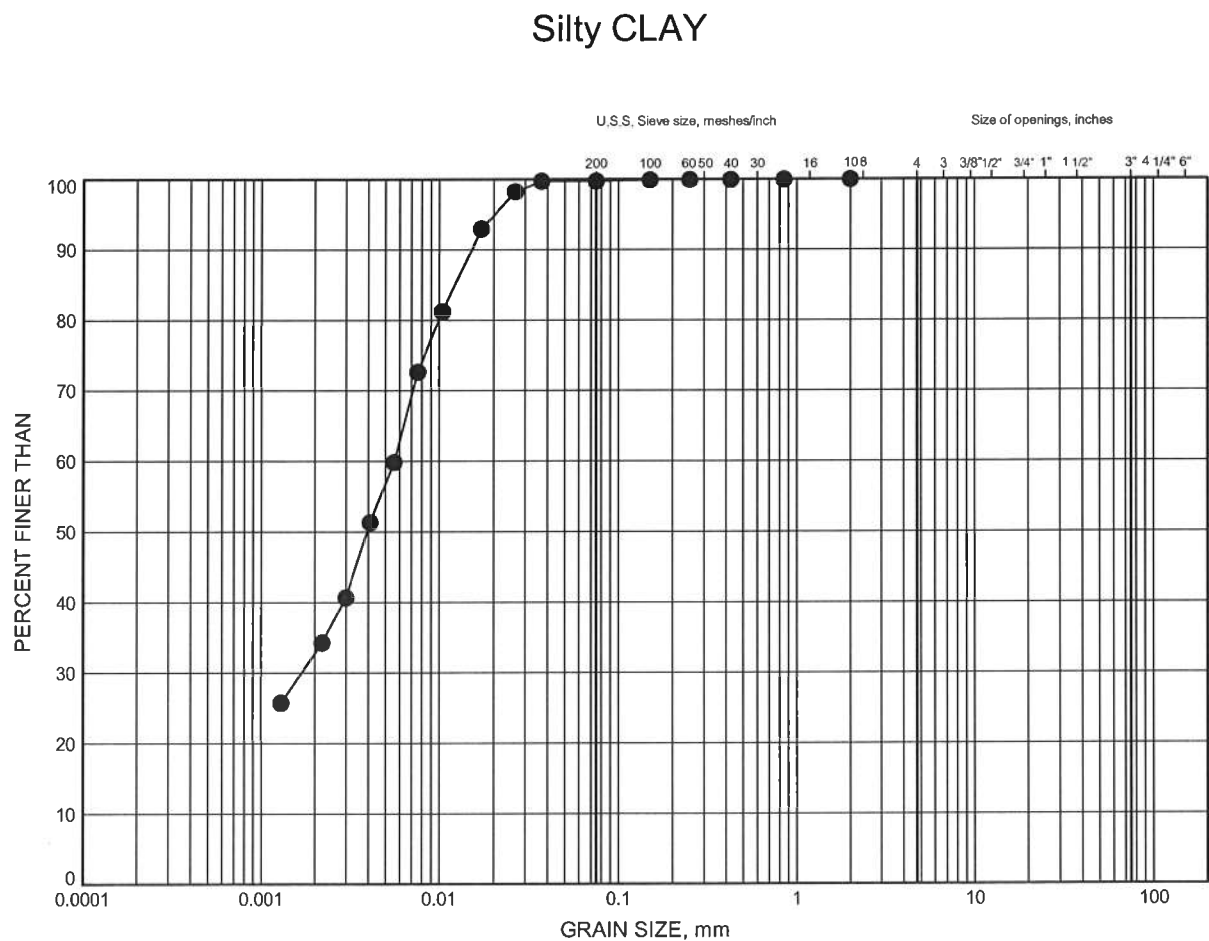
LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	CC11-01	9.45	213.17
⊠	CC11-01	14.02	208.60
▲	CC11-01	20.12	202.50
★	CC11-02	21.64	200.88
⊙	CC11-03	14.02	208.46
⊕	CC11-03	20.12	202.36



NWR 32 Rehabs
GRAIN SIZE DISTRIBUTION

FIGURE B4



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	CC11-02	14.02	208.50



W.P.# 6932-10-00
Prepared By MFA
Checked By MRA

Appendix C
Photographs, Figures and Tables



Photograph 1: South end of Cash Creek culvert.



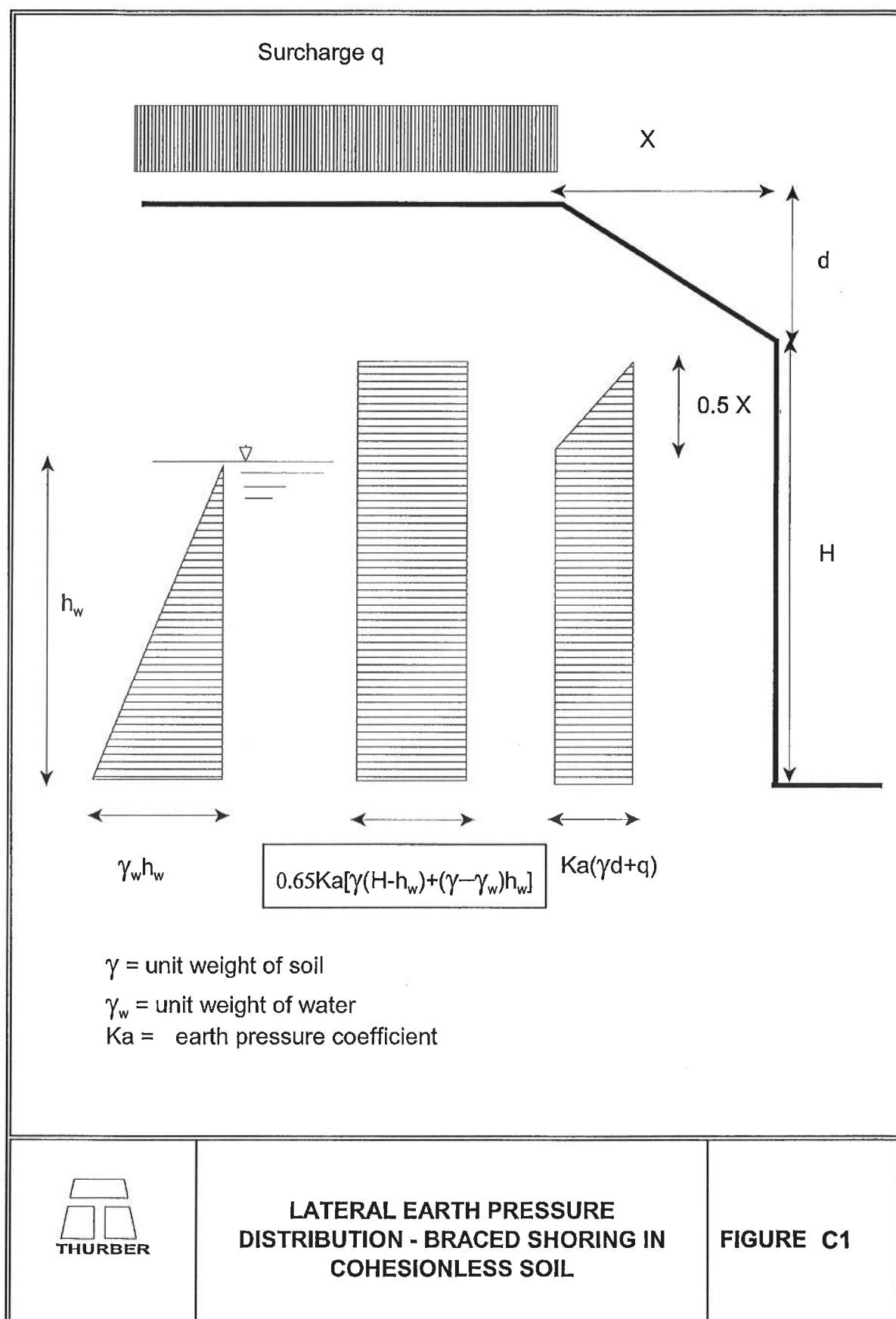
Photograph 2: North end of Cash Creek culvert.



Photograph 3: Creek valley from top of roadway embankment.



Photograph 4: Highway 11 over culvert location.



COMPARISON OF FOUNDATION ALTERNATIVES

Driven Sheet Piles	Driven H-Piles	Footings on Native Soil	Caissons
<p>Advantages:</p> <ul style="list-style-type: none"> i. Ease of construction. ii. Provides shoring and foundation elements in one operation. iii. Installation of piles could continue in freezing weather. iv. Potentially minimizes volume of excavation and roadway protection requirements. v. Minimizes potential for disturbance of streambed. <p>Disadvantages:</p> <ul style="list-style-type: none"> i. Unconventional design. ii. Specialized design features and construction required to provide drainage from behind wall and protection against frost action. iii. Cost of sheet piles. <p>RECOMMENDED</p>	<p>Advantages:</p> <ul style="list-style-type: none"> i. Piles will develop geotechnical resistance by shaft friction in loose to compact silt. ii. Installation of piles could continue in freezing weather iii. Foundation construction may require less volume of excavation than footings. <p>Disadvantages:</p> <ul style="list-style-type: none"> i. Higher unit costs than footings. ii. Relatively low axial and lateral resistance available. iii. Pile lengths required to achieve design resistance may vary. <p>FEASIBLE</p>	<p>Advantages:</p> <ul style="list-style-type: none"> i. Generally less costly construction than deep foundation elements. ii. Conventional culvert design or precast box installation is feasible. <p>Disadvantages:</p> <ul style="list-style-type: none"> iii. Low available geotechnical resistance in native silt deposit. iv. Excavation to base of existing roadway embankment is required for footing construction, requiring extensive roadway protection and excavation shoring. v. Dewatering and stream diversion will be required. vi. Potential disturbance of creek during excavation. <p>Open Footing Culvert: NOT RECOMMENDED</p> <p>Precast Box Culvert: FEASIBLE</p>	<p>Advantages:</p> <ul style="list-style-type: none"> i. Construction of caissons could continue in freezing weather. <p>Disadvantages:</p> <ul style="list-style-type: none"> i. No suitable bearing stratum was encountered within the depth of borehole exploration. ii. Higher cost than spread footings. iii. Specialized installation measures such as temporary liners and drilling mud will be required to install caissons in cohesionless silt under the water table. iv. Potential difficulty in cleaning and inspecting bases. <p>NOT RECOMMENDED</p>

Appendix D

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 511
- OPSS 539
- OPSS 804
- OPSS 902
- OPSS 903
- OPSD 803.010
- OPSD 810.010

2 Suggested Text for NSSP on Dewatering

Dewatering shall be provided by the Contractor during structure excavation and backfilling as per OPSS 902. The Contractor is advised that the soils underlying this site are cohesionless in nature and the observed groundwater table lies close to the surface at the embankment base. Excavation below the groundwater level is expected to lead to instability and slough of the sides of the excavation and boiling of the base, accompanied by loss in geotechnical resistance of the soils. If excavation is required to be carried out below the groundwater level prevailing at the time of construction, appropriate means of dewatering must be implemented to depress the groundwater level sufficiently far below the base of the excavation to prevent any instability, sloughing, or boiling and so as to preserve the stability of the excavation and to allow the work to proceed in the dry.

Appendix E

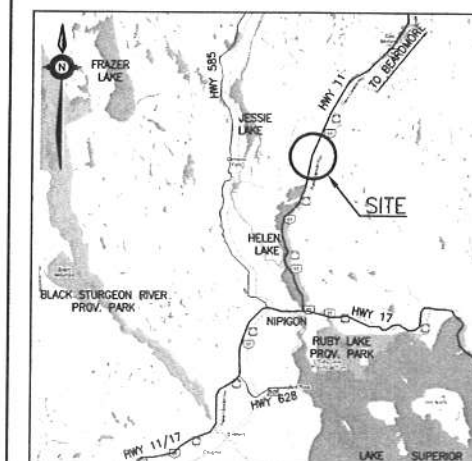
Drawing titled “Borehole Locations and Soil Strata”

DIMENSIONS ARE IN METRES
AND/OR MILLIMETRES
UNLESS OTHERWISE SHOWN

SHEET
10








THURBER ENGINEERING LTD



KEYPLAN

LEGEND

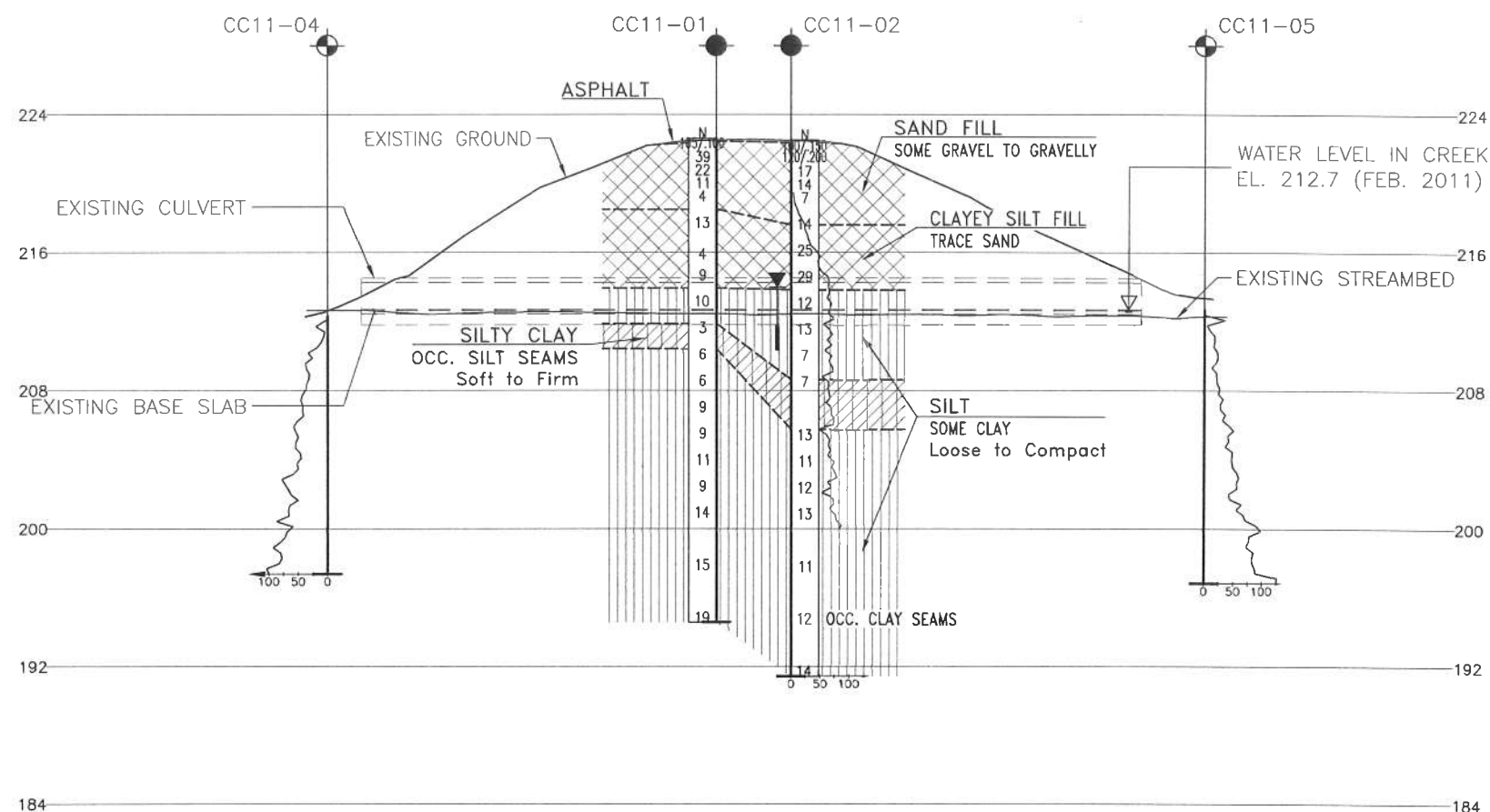
- | | |
|---|---------------------------------------|
|  | Borehole |
|  | Cone (DCPT) |
| N | Blows /0.3m (Std Pen Test, 475J/blow) |
| CONE | Blows /0.3m (60° Cone, 475J/blow) |
| PH | Pressure, Hydraulic |
|  | Water Level during Drilling |
|  | Water Level in Piezometer |
|  | Piezometer |
| 90% | Rock Quality Designation (RQD) |
| A/R | Auger Refusal |

[illegible]

-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. 52H-17



SECTION A-A ALONG C OF CULVERT

[illegible]