Appendix A – Geotechnical Investigation Reports for Mile 22.15 and 41.3

FINAL REPORT
GEOTECHNICAL INVESTIGATION
GREATER WINNIPEG WATER DISTRICT
RAILWAY BRIDGE MILE 22.15
RM OF SPRINGFIELD, MANITOBA

Submitted to:

Stantec Consulting Ltd.

100 – 1355 Taylor Avenue
Winnipeg, Manitoba
R3C 3Y9

Submitted by:

AMEC Environment & Infrastructure
A Division of AMEC Americas Limited

440 Dovercourt Drive
Winnipeg, Manitoba
R3Y 1N4
Office: (204) 488-2997
Fax: (204) 489-8261

5 February 2014

WX17312

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1.0 INTRODUCTION

At the request and authorization of Mr. Mike Boissonneault, P.Eng., Project Manager, and Senior Associate for Stantec Consulting Ltd (Stantec), AMEC Environment & Infrastructure, a division of AMEC Americas Limited (AMEC), completed a geotechnical investigation for the proposed replacement of the Greater Winnipeg Water District (GWWD) railway bridge located at Mile 22.15 in the RM of Springfield, Manitoba. The purpose of the geotechnical investigation was to verify the subsurface soil and groundwater conditions at the site in order to provide geotechnical recommendations for foundation design and construction. The scope of work for the project was outlined in AMEC's proposal number WPG2013.557, dated 3 December 2013. The geotechnical investigation was completed under subcontract to Stantec, Stantec Project Number and Subconsultant Agreement 113732050.

This report summarizes the field and laboratory testing programs, describes the subsurface conditions encountered at the test hole locations, and presents geotechnical engineering recommendations for: driven steel pile foundation alternatives; frost design considerations; abutment backfill and lateral earth pressures; and foundation concrete. Slope stability analyses, embankment settlement analyses, and pore pressure and fill staging analyses were not part of the scope of work for this geotechnical investigation. AMEC has assumed that these analyses are being undertaken by others as required for design.

2.0 SITE AND PROJECT DESCRIPTION

2.1 Site Description

The GWWD Mile 22.15 site is located within the RM of Springfield, near the intersection of Edgewood Road and Centreline Road. Specifically, the site is located about 550 m west of Edgewood Road, where the GWWD Rail Line crosses Cook's Creek.

At Mile 22.15, the GWWD rail line consists of a single track with a siding located on the east side of the crossing. Currently the crossing consists of a double span wooden bridge, supported on timber piles. Head walls at the abutments consisted of wooden lagging supported by steel piles. Installation depths, for both the wooden foundation piles and steel abutment piles, as well as sizing details, was not known. Rip-rap appeared to have been placed on both sides of the crossing, both under the bridge and extending out from the bridge on both sides. The thickness, material type, total quantity, and total coverage area of the rip-rap could not be determined due to snow cover. Photos of the site at the time of the geotechnical investigation are provided in Appendix A.

Cook's Creek is oriented relatively perpendicular to the existing bridge structure. Drainage ditches providing drainage into Cook's Creek were present along both sides of the rail embankment. Generally, the site is surrounded by flat-lying farm fields, with the rail track elevated about 1 to 2 m above the surrounding fields and ditches, respectively. On the north side of the site, a siphon for the City of Winnipeg aqueduct is present.

At the time of the geotechnical investigation, the farm fields surrounding the site, as well as the rail embankment, were covered by snow. Access to the site was gained via the rail line, which had been closed to rail traffic by the City of Winnipeg at the request of Stantec in order to provide a safe work area for drilling.

2.2 Proposed Development

It is understood that the proposed development at Mile 22.15 consists of a full replacement of the existing wooden bridge. Exact details of the proposed bridge were not known, however AMEC understood that the new structure will be a single span structure of approximately equal size to the existing structure. Based on information provided by Stantec, AMEC understood that steel HP310x110 piles are the preferred foundation type. Foundation loads were not available at the time of this report.

3.0 GEOTECHNICAL INVESTIGATION PROGRAM

Prior to initiating drilling, AMEC notified public utility providers (i.e. Manitoba Hydro, MTS, City of Winnipeg, etc.) of the intent to drill in order to clear public utilities, and where required, met with said representatives on-site.

On 16 December 2013, AMEC supervised the drilling of two test holes (TH01 and TH02) at the approximate locations illustrated in Figure 1. The test holes were drilled using an Acker MP5 track mounted drill rig equipped with 125 mm diameter solid stem augers; operated by Maple Leaf Drilling Ltd. of Winnipeg, Manitoba.

During drilling, AMEC field personnel visually classified the soil stratigraphy within the test holes in accordance with the Modified Unified Soil Classification System (MUSCS); as well as noted any observed seepage and/or sloughing conditions. Grab samples were collected at selected depths and retained in sealed plastic bags for shipping, review, and select testing in AMEC's Winnipeg laboratory. Shelby tube samples were also collected at selected depths for possible laboratory testing. The in-situ relative consistency of cohesive overburden was evaluated within the test hole using pocket penetrometer readings. The recorded pocket penetrometer readings are shown on the test hole logs. The relative consistency of underlying till was evaluated using standard penetration tests (SPTs), where the number of blows to drive the SPT sampler 0.3 m into the soil was recorded. The recorded number of blows is shown on the test hole logs as the SPT (N) value.

Upon completion of drilling, the depth to slough and groundwater level within each test hole was obtained after an elapsed time of about 10 minutes. Subsequently, the test holes were backfilled to grade with bentonite and auger cuttings. Excess auger cuttings were left neatly on site. UTM coordinates of the test hole locations were obtained using a hand held Garmin GPS, and are summarized in Table 3-1.

Table 3-1: Testhole Coordinates (UTM)

Testhole ID	Northing	Easting	Local Elevation[1] (m)
TH01	5524052	662681	~ 99.7
TH02	5524050	662706	~ 99.7

1. Local elevation 100.0 m assigned to top of track.

Following completion of the field drilling program, a laboratory testing program was conducted on selected soil samples obtained from the test holes. The laboratory testing program consisted of moisture content determinations, three unconfined compressive strength tests, and one set of liquid limit and plastic limit determinations.

Detailed test hole logs summarizing the sampling, field testing, laboratory test results, and subsurface conditions encountered at the test hole locations are presented in Appendix B. Actual depths noted on the test hole logs may vary by ± 0.3 m from those recorded due to the method by which the soil cuttings are returned to the surface. Summaries of the terms and symbols used on the test hole logs and of the Modified Unified Soil Classification System are also presented in Appendix B.

4.0 SUBSURFACE CONDITIONS

4.1 Stratigraphy

Consistent with the regional geology and anticipated conditions, the stratigraphy at the test hole location consisted of the following, in descending order from grade level:

- Sand Fill or Clay Fill
- Clay
- Silt (Till)

A brief description of each of the soil layers bulleted above is presented below: For detailed descriptions, the test hole logs in Appendix B should be consulted.

Sand Fill and Clay Fill

Weathered clay, with trace organics, likely comprising fill, was encountered at the surface of TH01 and extended to about 1.2 m below grade. The clay was generally described as medium to high plastic with some silt, frozen, and black with some organics and trace rootlets. A single moisture content determination on a thawed sample indicated an in-situ moisture content of about 37 percent.

Sand fill was encountered at the surface of TH02 and extended to about 0.5 m below grade. The sand was generally described as gravelly, poorly graded, medium to coarse grained, frozen, and brown. A single moisture content determination on a thawed sample indicated an in-situ moisture content of about 13 percent.

Clay

Clay was encountered beneath the organic clay (TH01) and sand fill (TH02) and extended to about 7 m below surface. The clay was silty, high plastic, moist, stiff becoming firm below 3.0 m, and dark grey. In-situ moisture contents within the clay ranged from 35 percent to 51 percent. Unconfined compressive strength tests were completed on one Shelby tube sample collected from TH01 and two Shelby tube samples collected from TH02; the results of which are summarized in Table 4-1.

Table 4-1: Summary of Unconfined Compressive Strength Tests

Test Hole	Depth (m)	UCS (kPa)	ε100 (%)	ε50 (%)	Bulk Density (kg/m^3)	Moisture Content (%)
TH01	4.6 – 5.2	103	4.5	0.9	1744	51.4
TH02	3.0 – 3.6	106	6.6	1.2	1830	42.4
TH02	6.1 – 6.7	95	5.1	1.2	1900	37.0

ε100 equals strain at maximum unconfined compressive stress.
ε50 equals strain at one half of maximum unconfined compressive stress

Silt(Till)

Glacial silt till was encountered beneath the clay in both test holes at about 7.0 m below grade, and extended to auger and practical refusal in TH01 at about 8.7 m below grade, and to auger refusal in TH02 at about 16.2 m below grade. The till comprised a low plastic silt matrix containing some sand, trace to some gravel, trace clay, and was wet becoming moist below 9 m. In-situ moisture contents within the till ranged from about 20 percent at the clay/till interface to about 8 to 10 percent below 9 m at TH02. Atterberg Limits testing on a sample of the silt collected from TH02 at about 12.2 m below grade indicated a liquid limit of about 16 percent, and a plastic limit of about 9 percent.

SPT ‘N’ values ranged from 16 and 9 near the top of the till (i.e. 7.6 m below grade) in TH01 and TH02 respectively; to in excess of 50 blows per foot at all other depths, suggesting compact to very dense conditions.

4.2 Groundwater and Sloughing Conditions

Seepage and sloughing conditions were noted during drilling, and the depths to the accumulated water levels within the test holes were measured about ten minutes after drilling.

Sloughing of the silt till was noted during solid stem auger drilling at TH01 below 7.0 m. Sloughing during drilling did not occur at TH02.

Slight seepage within the silt till at TH01 and moderate seepage within the silt till at TH02 were observed during drilling. Slight seepage within TH01 was observed between grade and 3.7 m below grade, as well as between 4.6 m and 8.1 m below grade.

Upon completion of drilling and removal of the augers, TH01 and TH02 remained open to 8.5 m below grade and 11.6 m below grade, respectively. The depth to accumulated water was measured in TH01 at 7.9 m below grade, and within TH02 at about 4.0 m below grade.

Seepage water within both boreholes is considered likely as originating as groundwater originating from the till. For design purposes per the recommendations outlined in this report, a groundwater table of 4 m below top of track (i.e. local elevation 96 m) is recommended. It should be noted that only short-term seepage and sloughing conditions were observed and that groundwater levels can fluctuate annually, seasonally or as a result of construction activity.

5.0 GEOTECHNICAL RECOMMENDATIONS

5.1 General Evaluation

The stratigraphy and soil conditions encountered within the test holes advanced at the site is considered typical of conditions within the region and are considered favourable for the proposed development.

From a foundations perspective, soil conditions are considered suitable for the use of the driven steel H-piles indicated as preferred by Stantec. Driven steel pipe piles are also regarded as a suitable pile foundation alternative. Other suitable pile alternatives included bored concrete piles bearing within the underlying silt till. However, given Stantec's indicated preference for driven Steel H-Piles and the fact that the existing structure is supported on a driven pile type, foundation recommendations here-in are limited to driven steel HP and pipe piles. Recommendations for other foundation alternatives can be provided upon request.

The following sections provide discussion and recommendations as they pertain to: driven steel piles; lateral earth pressures on below grade walls; frost design considerations; and foundation concrete.

5.2 Driven Steel Pile Foundations

As previously discussed, soil conditions at the site are considered suitable for the use of the driven steel H-piles indicated as preferred by Stantec, as well as pipe piles. Notwithstanding, the following conditions should be considered in final selection and design of piles:

- The underlying silt till at the site is very dense below 9 m and depending on selection of the pile type (i.e. H-Pile, open-ended, or closed-ended pipe), end bearing development could vary with pile type and location. H-piles are anticipated to penetrate deeper than open ended or closed ended pipe piles.
- High end-bearing development within the silt till could inhibit pile penetration below local elevation 91 m (i.e. beyond 9 m below test hole elevation) and the achievable embedment depth for tensile (uplift) resistance to transient uplift loads and frost. In this regard, pile type selection and sizing as well as selection of the piling hammer and appurtenances must consider both the compressive and tensile requirements of

the pile, and the ability to both achieve the required compressive capacity and achieve the minimum embedment depth required for uplift resistance.

AMEC understands that the foundation will be designed in accordance with the 2013 AREMA Manual for Railway Engineering. AMEC's interpretation of recommended practices outline in the manual is that foundation design employs allowable stress design (ASD) principles as opposed to Limit State or Load-Factor Resistance Design (LFRD) design principles. In this regard, parameters here-in have been presented for use in ASD. If parameters for alternative design principles (i.e. Limit States) are required, this office should be contacted for revisions.

5.2.1 Axial Compressive Resistance of Single Driven Steel Piles

The 'allowable' compressive resistance of a driven steel pile (H or pipe) as a function of embedment depth may be determined using the 'allowable' unit shaft friction and unit end bearing pressures recommended in Table 5-1.

Table 5-1: 'Allowable' Unit Shaft Friction & End Bearing Values for Driven Steel Piles

Elevation Range[1] (m)	Assumed Average Soil Type	Shaft Friction (kPa)	End Bearing (kPa)
99.7 to X[2]	Fill and Clay	0	--*
X to 93.0	Clay	16	--*
93.0 to 91.0	Silt Till (Compact)	18	350
91.0 to 84.0 m	Silt Till (Very Dense)	48	1,600

[1] The elevations presented assume top of track to be approximate local elevation 100.0 m.
[2] X = the elevation of the frost penetration front at the pile interface, determined in accordance with the recommended frost penetration depth presented in Section 5.4, to account for possible movement of the soil away from the perimeter of the pile.

The above 'allowable' unit shaft friction and 'allowable' unit end bearing values include a factor of safety of 2.5.

For all pipe pile types and sizes, shaft friction should only be applied to the exterior surface area of the pile. In the case of steel H piles, shaft friction may be applied to the exterior sides of the two flanges plus twice the depth of the web (i.e. the box perimeter). For pipe piles with a closed-end configuration, end bearing may be applied to the full cross-sectional area of the toe of the pile. For H-piles and open end pile configurations, the area over which end bearing may be applied varies with the pile diameter. For small diameter pipes piles (i.e. DN300 or smaller) and H-Piles, there is considered a higher potential for 'plugging' of the pile during installation, and as such, it is considered acceptable to apply the end bearing to the full cross-sectional area of the toe of the pile which may be taken as the area enclosed by the outer circumference of a pipe section, or the cross sectional area of a rectangle bounded by the flanges in the case of steel H sections. For larger pile sizes, 'plugging' of the pile during driving may be variable, and the end bearing values provided above should be re-evaluated by AMEC for large diameter pipe piles. However, for current design purposes, the unit end bearing values outlined above may be applied to the steel area of the toe of pipe piles larger than DN300. If during construction driving resistance is lower or higher than anticipated, 'soil plug' development and end bearing development may be quantified via dynamic pile testing by pile driving analyzer (PDA Testing) and CAPWAP[1] analysis.

Due to limitations on the driveability of the pile imposed by the yield strength of the pile, as a guide to initial design and selection of pile wall thickness and steel grade, it is recommended that the maximum design 'allowable' compressive resistance of a steel pile be limited to 0.25FyAs (i.e. a fraction of the unfactored structural yield capacity of the pile), where: Fy is the nominal yield stress of the steel, and As is the cross-sectional area of steel in the pile. The purpose of this restriction is to mitigate the risk of statically designing a pile that cannot be driven with enough energy or force to overcome dynamic soil resistance and subsequently develop the design static load resistance without yielding or damaging the pile. Subject to driveability analysis and evaluation of driving stresses at the pile design stage, the maximum 'allowable' compressive stress could be increased to as much as 0.35FyAs.

Additional comments for design and construction of driven steel piles are as follows:

- Static pile design parameters pertain to soil resistance only. The pile cross sections must be designed to withstand the design loads and the driving forces during installation.
- Although not commonly employed for the installation of driven piles, if a pre-bore was required (i.e. for ground disturbance clearance or contractor preference), shaft friction must be neglected over the depth of the pre-bore.
- Piles must be spaced a minimum of three pile diameters apart, as measured from centre-to-centre, in order to act individually as single piles in vertical compression when used in a small pile group of three piles or less. Where pile groups larger than 3 piles are required, the pile group should be reviewed by AMEC.
- Once the pile configuration is known, AMEC recommends that a driveability analysis (i.e. WEAP) be completed prior to proceeding to construction, and concurrent with selection of the pile driving equipment, to confirm the ability of the hammer and appurtenances to drive the piles to the design capacity and embedment depth without damage. Similarly, the driveability analysis can be extended to develop termination criteria for use in pile installation monitoring. It should be noted that driveability analyses should be completed using ultimate soil parameters.
- All piles driven within five pile diameters should be monitored for heave and, where heave is observed, piles should be re-driven. Piles that are re-driven should be advanced to at least the original elevation.
- All piles should be driven continuously to practical refusal once driving is initiated.
- Any piles that are have been damaged, are excessively out of plumb, or have refused prematurely may need to be replaced, pending a review by a qualified geotechnical engineer of their load carrying capability and estimated settlement.
- All pile caps and grade beams should be underlain by a minimum 150 mm thick void form to accommodate the expansive nature and potential frost heave of the underlying soil.

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[1] PDA : Pile Driving Analyzer, CAPWAP: software to analyze PDA Test data

- Prior to the pile installation, the piles should be inspected to confirm that the material specifications are satisfied. As a minimum, steel H-piles should meet the requirements of CAN/CSA-G40.20/G40.21, Grade 350 W, and pipe piles should have a minimum yield strength of 310 MPa (i.e. ASTM A252 Grade 3 steel). The piles should be free from protrusions, which could create voids in the soil around the pile during driving.
- Monitoring of the pile installation by an experienced inspector is recommended to verify that the piles are installed in accordance with design assumptions and the driving criteria are satisfied. For each pile, a complete driving record in terms of the number of blows per 300 mm of penetration should be recorded by the inspector and reviewed during pile installation by the designer.

5.2.2 Tensile (Uplift) Resistance (Single Pile)

In the case of driven steel piles, the uplift resistance of a single pile will be provided by the sustained downward load on the pile (if applicable) and shaft friction along the length of pile embedded below the depth of frost penetration. In the case of straight shaft (i.e. driven steel) piles, the soil component of the 'allowable' uplift resistance to *sustained* tensile loads will be provided by shaft friction and can be determined using 70% of the shaft friction values outlined in Table 5-1. For pipe piles, only the exterior surface area of the pile in contact with the soil should be used in the calculation of the frictional resistance. In the case of steel H piles, the surface area should include the exterior sides of the two flanges plus twice the depth of the web. For frost and *transient* uplift loads, such as those due to wind gusts, no reduction of the shaft friction values in Table 5-1 is required. Transient loads would not be additive to the uplift forces due to frost action.

Although not commonly employed for the installation of driven steel piles, if a pre-bore was required (i.e. for ground disturbance clearance or contractor preference), shaft friction must be neglected over the depth of the pre-bore.

5.2.3 Lateral Resistance (Single Pile)

Piles resist laterally applied loads by deflecting until the necessary resistance is mobilized in the adjacent soils. The majority of lateral load resistance for flexible piles is generally provided within the upper 4 to 5 m of the soil profile (i.e. the typical point of inflection for the pile). The maximum bending moment typically occurs at 1.5 m to 3.0 m below grade depending on the applied loading and soil resistance. The allowable lateral capacity depends upon the properties of the soil and pile material, pile sizes, fixity of the top of the pile, depth of embedment, height of load application above ground, vertical load applied and tolerable deflections.

Where the lateral load capacities or magnitude of movements of piles are critical, it is recommended that the lateral deflections and design capacities of piles or groups of piles be evaluated using Reese's method of p-y curves. This method models the strength-deformation characteristics using load-displacement curves for the various soil strata, and the non-linear behaviour of the soil. With the method of p-y curves, solutions may be obtained through an iterative procedure performed using LPILE Software for single piles, and extended to pile groups by using GROUP Software to analyze the behaviour of piles in a group subjected to both axial and lateral loadings. The analytical procedure provides lateral pile deflections, generated bending moments, shear forces, and the soil reaction computed at close intervals over the depth of the pile.

Based on conditions observed within the appended test hole logs, the stratigraphy and soil parameters outlined in Table 5-2 are considered suitably representative of the average subsurface conditions expected to influence the lateral behaviour of driven steel piles at the Site.

Table 5-2: LPile Input Parameters

Elevation Range (m)[1]	Soil Type / Model	Effective Unit Weight (kN/m^3)[2]	Friction Angle (•)	Cohesion (kPa)	E50 (%)	p-y subgrade modulus, k (kPa/m)
100.0 to 96.0	Clay	19	n/a	50	0.012	Default
96.0 to 93.0	Clay	9	n/a	50	0.012	Default
93.0 to 84.0	Silt Till	10	35	0	n/a	Default

[1] The elevations presented assume top of track to be approximate local elevation 100.0 m.
[2] Groundwater level of 4.0 m below top of track was assumed.

The use of zero lateral resistance for cohesive soils (i.e. clay soils) located within 1 m of final surface is recommended for the serviceability condition where there exists the potential for formation of a permanent gap between the pile and the soil due to installation, desiccation, or frost effects.

Lateral pile analysis of a prescribed pile configuration was not part AMEC's scope of work for this investigation. Notwithstanding, lateral pile analysis could be conducted by AMEC for specified pile configurations on request.

5.2.4 Single Pile Settlement

The settlement of a single pile depends on the applied load, strength-deformation properties of the foundation soils, load transfer mechanism, load distribution over the pile embedment depth, and the relative proportions of the load carried by shaft friction and end-bearing. Assuming good workmanship, inclusive of good excavation, the predicted settlement of piles at working loads equal to a maximum given by the 'allowable' pile capacity are 0.5 to 1 percent of the shaft diameter plus the elastic shortening of the pile due to the compressive load acting on the pile.

5.2.5 Pile Group Effects

Generally, piles will behave individually in compression (i.e. group efficiency equals 1.0) when a minimum centre-to-centre spacing of 5 pile diameters is provided between adjacent piles, and will behave individually laterally when the center-to-center spacing is greater than 3 diameters in the direction transverse to loading (side-by-side), and greater than 8 diameters in the direction parallel to loading (in-line). However, for circumstances in which piles are closely spaced and/or the piles are connected by a rigid pile cap forcing equal settlement behaviour at the pile heads, interaction between the piles will occur and should be considered in design.

Notwithstanding the above, AMEC does not anticipate that large groups of four or more closely spaced piles will be required. Consequently, recommendations pertaining to the axial and lateral load resistances of pile groups are not provided here-in. If pile groups are required by design, AMEC should be notified and a review of possible group interactions effects evaluated.

5.3 Lateral Earth Pressures on Below Grade Walls (i.e. Wing Walls)

5.3.1 Soil Design Parameters

Below grade walls (i.e. wing walls) will be required to resist lateral pressures from the surrounding soil, water, and any additional surcharge loading (i.e. fill, live surface loads, etc.). Table provides recommended design values for the bulk unit weight, angle of internal friction, and 'at rest', active, and lateral earth pressure coefficients for moderately to well compacted native clay, compacted sand fill, and compacted gravel fill soils.

Table 5-3: Earth Pressure Coefficients and Soil Unit Weights

Soil Type		Active Pressure Coefficient K_a	"At Rest" Earth Pressure Coefficient K_o	Passive Pressure Coefficient[a] K_p	Total Soil Unit Weight (kN/m^3)	Friction Angle (deg) Between Soil and Concrete
Gravel Fill	Well Compacted	0.25	0.40	2.67	23	25
	Moderately Compacted	0.30	0.47	2.17	22	21
Sand Fill	Well Compacted	0.30	0.47	2.17	21	21
	Moderately Compacted	0.36	0.53	1.85	20	18
Common Clay Fill and Clay	In-situ and Well Compacted	0.53	0.70	1.26	19	12
	Moderately Compacted	0.59	0.75	1.13	18	10

The passive earth pressure coefficients provided in Table 5-3 include a reduction factor of 1.5 to account for the partial mobilization of passive resistance that is consistent with the small wall displacements expected under operational conditions. Relatively large wall displacements would be necessary to realize full passive resistances.

With respect to subsurface drainage and groundwater conditions over the depth of the foundation structure, the phreatic surface at the site should be taken as 4 m below top of track. The use of free draining backfill and the provision of drainage behind vertical subsurface walls is strongly recommended, and will further serve to mitigate frost action on vertical walls extending through the zone of frost penetration.

The magnitude and distribution of the lateral earth pressures on below grade structures will depend on such factors as the rigidity of the below grade structure; the degree of compaction of the backfill against the structure; the backfill soil type; the slope angle at the structure/soil interface; and the subsurface drainage and groundwater conditions over the height of the structure. It is anticipated that a sloped excavation will be implemented for construction of below grade foundation structures, which will necessitate the placement of backfill behind below grade structure walls. The magnitude and distribution of the lateral earth pressures (P) on below grade structures will depend on the degree of compaction of the backfill. In addition to earth pressures, lateral stresses generated by any applicable surcharge loads also need to be evaluated in the design. Recommended earth pressure distributions for moderate to well compacted backfill cases, as well as for line or point surcharge loads, are discussed in Section 5.3.2.

5.3.2 Calculation of Earth Pressure Distributions and Load Factors

5.3.2.1. Moderate to Well Compacted Backfill Case

Where subgrade support on the surface of the retained soil behind a wall is required, as it is for headwalls, the backfill against the wall will need to be compacted to at least 95 percent Standard Proctor maximum dry density. The use of free draining backfill behind below grade structures is strongly recommended in order to maintain drained conditions behind the structure. Assuming drained conditions, the design earth pressure distribution should adopt a combined trapezoidal/triangular distribution as shown on Figure 2 to account for the induced lateral pressures due to compaction. Figure 2 also provides the relationships to be used in the calculation of the compaction induced earth pressures, and tabulated loads (P) generated by typical compactors. The earth pressure coefficients to be used in the calculation of the lateral pressures should be those applicable to the backfill types given in Table 5-3.

If sub-drainage is not provided and it is possible by design for a perched groundwater to develop within the retained soil (i.e. “bathtub” effect associated with gravel fill soils surrounded by low permeable fine grained soil types), the hydrostatic component should be included in addition to the earth pressure given in Figure 2.

5.3.2.2. Surcharge Loads

In addition to earth pressures, lateral stresses generated by surcharge loads, such as point loads from locomotives, also need to be evaluated in the design. For line or point surcharge loads, the lateral pressures should be determined using the relationships given in Figure 4. In the case of uniformly distributed surcharge loads, such as those acting on the surface of the retained soil, the induced lateral earth pressure may be determined by multiplying the surcharge load by the appropriate earth pressure coefficient.

5.4 Frost Design Considerations

5.4.1 Frost Penetration Depth

The upper stratigraphy at the test hole locations, and across the site, is considered moderately frost susceptible in the presence of water, and as such, frost effects should be considered for foundations or surface structures sensitive to movement. Based on historical temperature data for the area, a design frost penetration of 2.4 m below final grade is recommended in unheated areas that will not have regular snow or vegetative ground cover. It should be noted that this recommended frost penetration depth extends both vertically and laterally behind final surface (i.e. extends 2.4 m behind the headwall).

5.4.2 Pile Foundations

Frost forces applied to pile foundations include adfreeze pressures acting along the pile shafts within the depth of frost penetration. If pile caps are used and extend beyond the perimeter of the underlying pile, then frost heave forces acting on the undersides of the pile caps, as well as any connecting supports (i.e. lateral tie between the piles) will also need to be considered.

5.4.2.1. Frost Heave

To reduce the potential of frost heave pressures, a void-forming product should be installed beneath the underside of the pile caps and any other structural element located within the depth of frost penetration. The recommended minimum thickness of the void should be 150 mm. Alternatively, a compressible material may be used in lieu of a void forming material, and the uplift pressures may be taken as the crushing strength of the compressible medium. It is recommended that a frost heave of 150 mm be assumed in determining the required thickness for the void-filler and the associated uplift pressures associated with the thickness used.

The finished grade adjacent to each pile cap should be capped with well compacted clay and sloped away so that the surface runoff is not allowed to infiltrate and collect in the void space or in the compressible medium.

The use of void-forming product below the groundwater is unfeasible. In instances where groundwater is located within the recommended depth of frost penetration, the underside of foundation elements such as pile caps should extend below the depth of frost penetration to mitigate frost heave development on the underside of the foundation element.

5.4.2.2. Adfreeze Stresses

Resistance to adfreeze and frost heave forces will be provided by the sustained vertical loads on the foundation, the buoyant weight of the foundation and dead weight of the structure, and the soil uplift resistance component provided by the length of the pile extending below the depth of frost penetration. In the case of straight shaft (i.e. driven steel) piles, the adfreeze force acting on the pile may be determined assuming an unfactored unit adfreeze stress of 65 kPa applied to the exterior surface of the pile and supported foundation elements (i.e. pile caps) located within the zone of frost penetration. The uplift resistance of the pile below the depth of frost may be determined using the Tensile (Uplift) Resistance recommendations presented in Section 5.2.2.

5.5 Foundation Concrete

Where concrete elements outlined in this report and all other concrete in contact with the local soil will be subjected in service to weathering, sulphate attack, a corrosive environment, or saturated conditions, the concrete should be designed, specified, and constructed in accordance with concrete exposure classifications outlined in the latest edition of CSA standard A23.1, Concrete Materials and Methods of Concrete Construction. In addition, all concrete must be supplied in accordance with current Manitoba and National Building Code requirements.

Based on significant data gathered through previous work in Southern Manitoba, water soluble sulphate concentrations in the soil are typically in the range of 0.2% to 2.0%. As such, the degree of sulphate exposure at the site may be considered as 'severe' in accordance with current CSA standards, and the use of sulphate resistance cement (Type HS or HSb) is recommended for concrete in contact with the local soil. Furthermore, air entrainment should be incorporated into any concrete elements that are exposed to freeze-thaw to enhance its durability.

It should be recognized that there may be structural and other considerations, which may necessitate additional requirements for subsurface concrete mix design.

5.6 Construction Monitoring and Testing

All engineering design recommendations presented in this report are based on the assumption that an adequate level of testing and monitoring will be provided during construction and that all construction will be carried out by a suitably qualified contractor experienced in foundation and earthworks construction. An adequate level of testing and monitoring is considered to be:

• for earthworks:	full-time monitoring and compaction testing.
• for deep foundations:	design review and full time monitoring during construction.
• for concrete construction:	testing of plastic and hardened concrete in accordance with the latest editions of CSA A23.1 and A23.2; and review of concrete supplier's mix designs for conformance with prescribed and/or performance concrete specifications.

AMEC requests the opportunity to review the design drawings, and the installation of the foundations, to confirm that the geotechnical recommendations have been correctly interpreted. AMEC would be pleased to provide any further information that may be needed during design and to advise on the geotechnical aspects of specifications for inclusion in contract documents.

6.0 CLOSURE

The findings and recommendations presented in this report were based on geotechnical evaluation of the subsurface conditions observed during the site investigation described in this report. If conditions other than those reported in this report are noted during subsequent phases of the project, or if the assumptions stated herein are not in keeping with the design, this office should be notified immediately in order that the recommendations can be verified and revised as required. Recommendations presented herein may not be valid if an adequate level of inspection is not provided during construction, or if relevant building code requirements are not met.

Soil conditions, by their nature, can be highly variable across a site. The placement of fill and prior construction activities on a site can contribute to the variability especially in near surface soil conditions. A contingency should always be included in any construction budget to allow for the possibility of variation in soil conditions, which may result in modification of the design and construction procedures.

This report has been prepared for the exclusive use of Stantec Consulting Ltd., and their agents, for specific application to the project described in this report. The data and recommendations provided herein should not be used for any other purpose, or by any other parties, without review and written advice from AMEC. Any use that a third party makes of this report, or any reliance or decisions made based on this report, are the responsibility of those parties. AMEC accepts no responsibility for damages suffered by a third party as a result of decisions made or actions based on this report.

This report has been prepared in accordance with generally accepted soil and foundation engineering practices. No other warranty, either expressed or implied, is made.

Respectfully submitted,
AMEC Environment & Infrastructure,
A Division of AMEC Americas Limited

5 Feb 2014
K. W.
JOHNSON
Member
24333

Certificate of Authorization
AMEC Environment & Infrastructure, a
Division of AMEC Americas Limited
No. 555 Date: 5 Feb 2014

Reviewed by:

Kelly Johnson

Kelly Johnson, P. Eng.
Senior Geotechnical Engineer

Harley Pankratz, P.Eng.
Vice President, Eastern Prairies/Northern Alberta

FIGURES

CLIENT LOGO

CLIENT

STANTEC CONSULTING LTD.

AMEC Environment & Infrastructure
440 DOVERCOURT DRIVE
WINNIPEG, MANITOBA R3Y 1N4
PHONE: 204.488.2997 FAX:204.489.8261

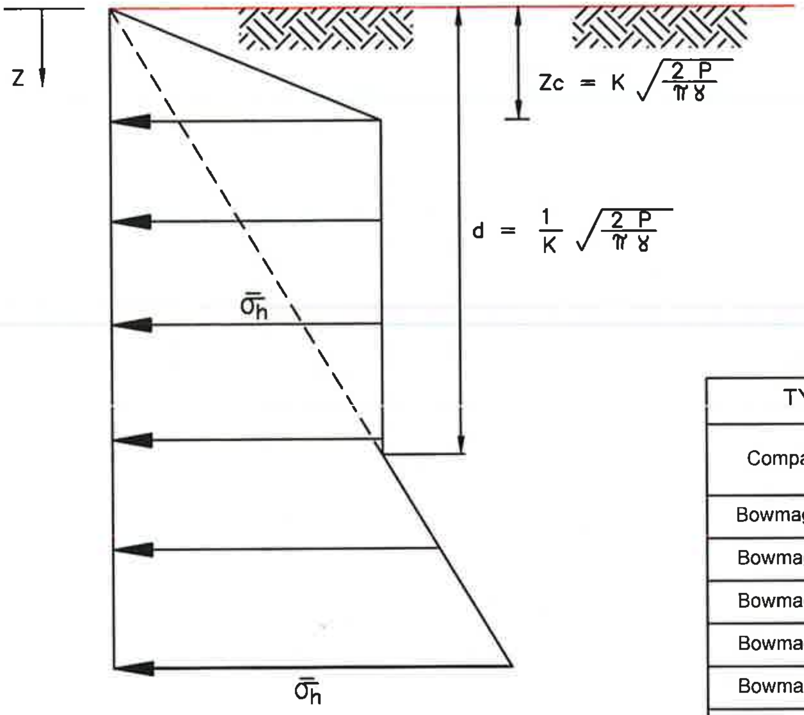
DWN BY: MD
CHK'D BY: TG
DATUM: NAD83
PROJECTION: UTM Zone 14 U
SCALE: AS SHOWN

GEOTECHNICAL INVESTIGATION
GREATER WINNIPEG WATER DISTRICT
RAILWAY BRIDGE MILE 22.15

TEST HOLE LOCATION PLAN

REV. NO.: A
DATE: FEBRUARY 2014
PROJECT NO: WX17312
FIGURE No. FIGURE 1

P:\JOBS\17300'S\17310'S\17312 STANTEC - GWWD BRIDGES\DRAWINGS\WX17312.DWG



EARTH PRESSURE DISTRIBUTION

FOR $Zc \leq Z \leq d$

$$\bar{\sigma}_h = \sqrt{\frac{2P\gamma}{\pi}}$$

FOR $Z > d$

$$\bar{\sigma}_h = K \cdot \gamma \cdot Z$$

TYPICAL COMPACTOR LOADS (P)			
Compactor	LOAD (P) kN/m	Compactor	LOAD (P) kN/m
Bowmag TSE	31	Bowmag BW122PD	36
Bowmag 60S	32	Bowmag 142PDB	47
Bowmag 65S	22	Bowmag 172PDB	93
Bowmag 75S	33	Dynapac LR100	42
Bowmag 90S	39	Dynapac 2100V	93
Bowmag 75AD	20	Dynapac CA121D	53
Bowmag 100AD	20	Dynapac CA121PD	54
Bowmag 120AD	34	Dynapac CA151	80
Bowmag 130AD	36	Dynapac CA151D	80
Bowmag BW122D	30	Dynapac CA151PD	96

$$P \text{ (ROLLER LOAD)} = \frac{\text{DEAD WT. OF ROLLER + CENTRIFUGAL FORCE}}{\text{WIDTH OF ROLLER}}$$

TYPICAL VALUES GIVEN IN TABLE

EARTH PRESSURE COEFFICIENTS

$K = K_o$ ("AT REST") OR K_a (ACTIVE CASE)
(SEE TEXT OF REPORT)

γ = SOIL UNIT WEIGHT
(SEE TEXT OF REPORT)

CLIENT:
STANTEC
CONSULTING LTD.

AMEC Earth & Environmental
5681-70 STREET, EDMONTON, ALBERTA, T6B 3P6
PHONE 780-436-2152, FAX 780-435-8425

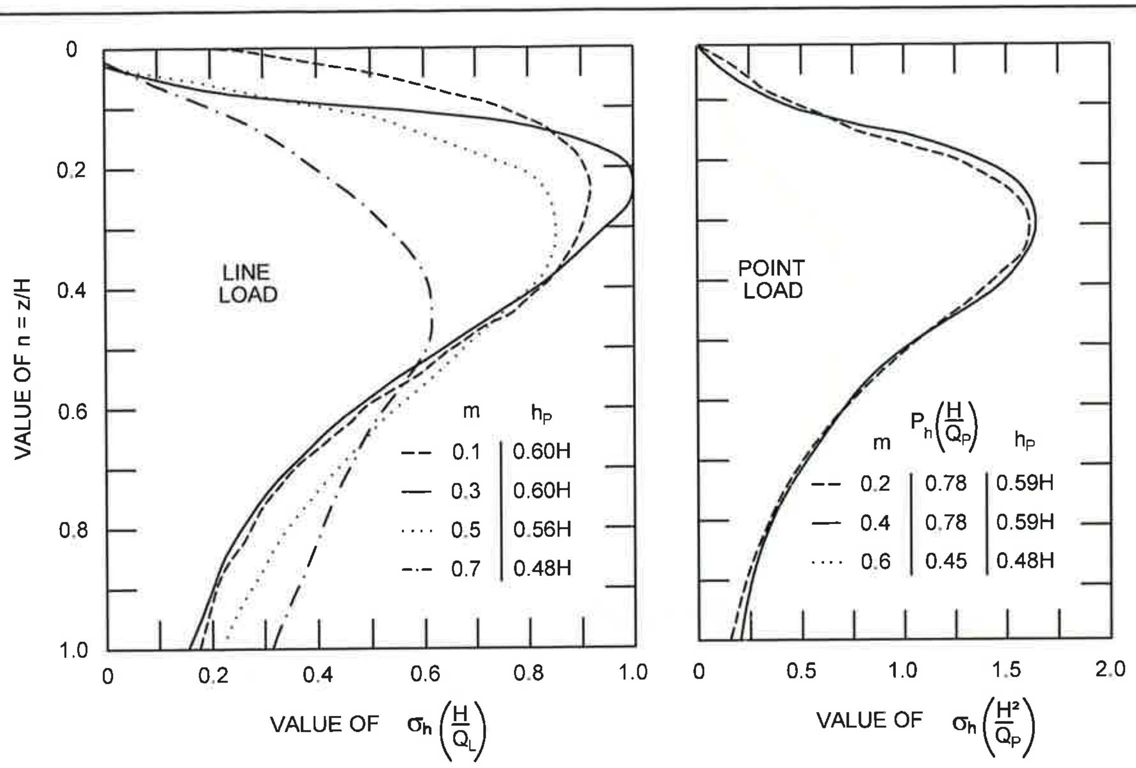
DWN BY: MD
CHK'D BY: KJ
DATUM: -
PROJECTION: -
SCALE: NOT TO SCALE

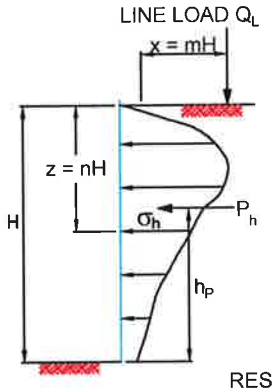
GEOTECHNICAL INVESTIGATION
GREATER WINNIPEG WATER DISTRICT
RAILWAY BRIDGE MILE 22.15

LATERAL EARTH PRESSURES
INDUCED BY COMPACTION

DATE: FEBRUARY 2014
PROJECT No.: WX17312
REV. No.: -
FIGURE No.: FIGURE 2

P:\Jobs\17300's\17310's\17312 Stantec - GWWD Bridges\Drawings\LAT PRESSURE - FIG 2.dwg - F2 - Jan. 31, 2014 10:40 AM - matthews.dolores





FOR m ≤ 0.4:

$$\sigma_h\left(\frac{H}{Q_L}\right) = \frac{0.20n}{(0.16 + n^2)^2}$$

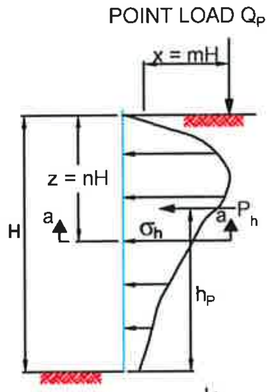
$P_h = 0.55\ Q_L$

FOR m > 0.4:

$$\sigma_h\left(\frac{H}{Q_L}\right) = \frac{1.28m^2n}{(m^2 + n^2)^2}$$

$$\text{RESULTANT } P_h = \frac{0.64\ Q_L}{(m^2 + 1)}$$

PRESSURES FROM LINE LOAD
(BOUSSINESQ EQUATION MODIFIED BY EXPERIMENT)



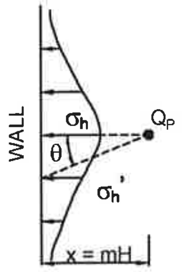
FOR m ≤ 0.4:

$$\sigma_h\left(\frac{H^2}{Q_P}\right) = \frac{0.28n^2}{(0.16 + n^2)^3}$$

FOR m > 0.4:

$$\sigma_h\left(\frac{H^2}{Q_P}\right) = \frac{1.77m^2n^2}{(m^2 + n^2)^3}$$

$$\sigma_h' = \sigma_h \text{ COS}^2\ (1.1\theta)$$



SECTION a-a
PRESSURES FROM POINT LOAD
(BOUSSINESQ EQUATION
MODIFIED BY EXPERIMENT)

CLIENT: STANTEC CONSULTING LTD.	DWN BY: MD CHK'D BY: KJ	GEOTECHNICAL INVESTIGATION GREATER WINNIPEG WATER DISTRICT RAILWAY BRIDGE MILE 22.15	DATE: FEBRUARY 2014 PROJECT No.: WX17312
AMEC Earth & Environmental 5681-70 STREET, EDMONTON, ALBERTA, T6B 3P6 PHONE 780-436-2152, FAX 780-435-8425	DATUM: - PROJECTION: - SCALE: NOT TO SCALE	LATERAL PRESSURES DUE TO SURCHARGE POINT AND LINE LOADS	REV. No.: - FIGURE No.: FIGURE 3

APPENDIX A

Photo 1: Existing Bridge Foundations, Looking Southeast.

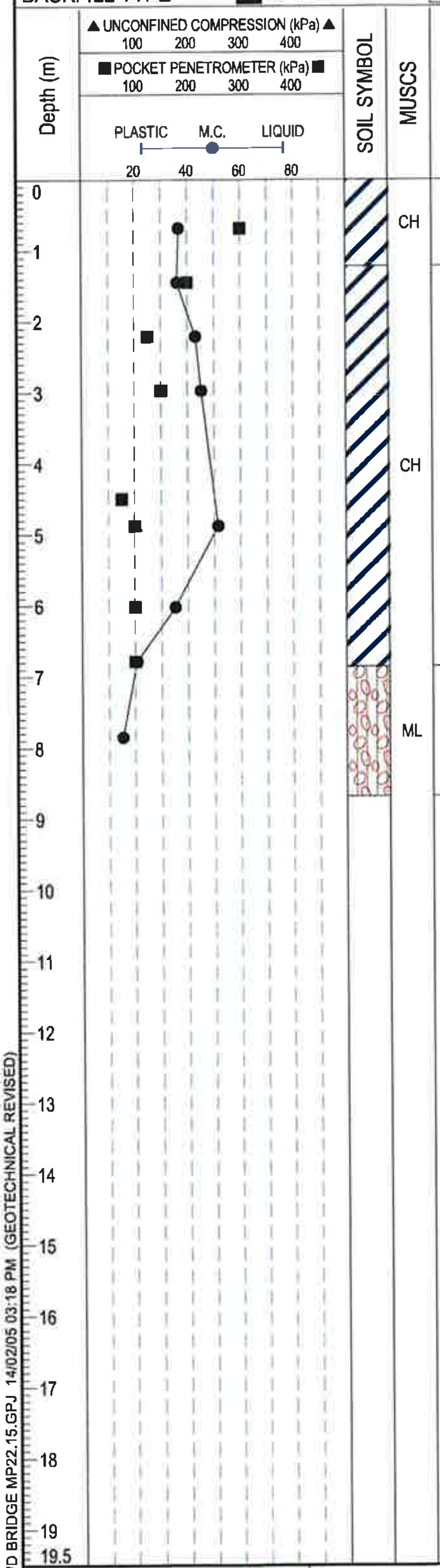
Photo 2: Existing Bridge Foundations, Looking North of east.

APPENDIX B

PROJECT: GWWD Bridges	DRILLED BY: Maple Leaf Drilling Ltd.	BORE HOLE NO: **TH01**
CLIENT: Stantec	DRILL TYPE: Acker MP5 Track Rig	PROJECT NO: WX17312
LOCATION: Anola, Manitoba	DRILL METHOD: 125 mm SSA	ELEVATION: 99.7 m

SAMPLE TYPE ■ Shelby Tube ▨ No Recovery ☒ SPT (N) ☰ Grab Sample ▥ Split-Pen ◧ Core

BACKFILL TYPE ■ Bentonite ☐ Pea Gravel ▨ Drill Cuttings ⁘ Grout ▥ Slough ⁘ Sand



SOIL DESCRIPTION

CLAY - some silt, medium to high plastic, frozen, very stiff, black, some organics, trace rootlets

CLAY - silty, high plastic, moist, stiff to very stiff, grey
- stiff, mottled brown, occasional sulphate inclusions below 1.5 m
- firm below 3.0 m
- firm to stiff, occasional to frequent silt till inclusions below 4.6 m
- frequent silt till inclusions below 6.1 m

SILT (TILL) - trace clay, some sand, trace gravel, low plastic, moist, compact, tan
- some gravel, no clay, wet below 7.6 m
- moist below 8.1 m

AUGER AND PRACTICAL SPT REFUSAL AT 8.7 m BELOW GRADE ON A SUSPECTED BOULDER

NOTES:
- Slight seepage was observed below 6.9 m. No sloughing was observed during drilling
- Test hole remained open to 8.5 m below grade with water measured at 7.9 m 10 min after completion
- Test hole was backfilled with auger cuttings and bentonite

SAMPLE TYPE	SAMPLE NO	SPT (N)
☰	1	
☰	2	
☰	3	
☰	4	
☰	5	
■	6	
☰	7	
☰	8	
☰	9	
☒	10	16
☰	11	
☰	12	50/50

COMMENTS

TH Coordinates (UTM):
5524052mN
662681mE

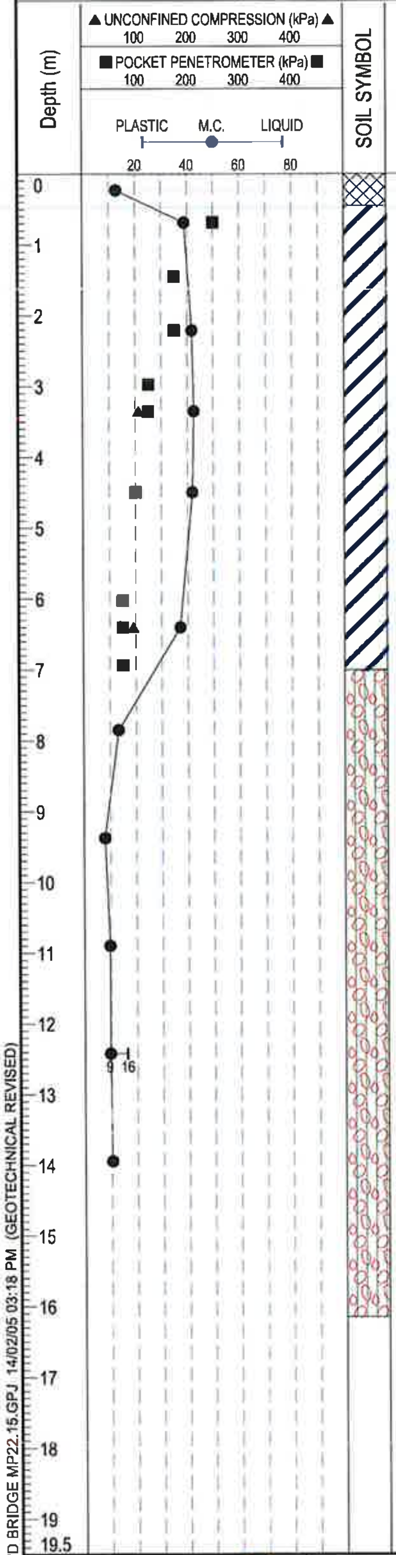
Unconfined Compressive Strength (S6):
Max Stress: 103 kPa
Strain @ Failure: 4.5%
Bulk Density: 1744 kg/m^3
Dry Density: 1151 kg/m^3

ELEVATION (m): 99, 98, 97, 96, 95, 94, 93, 92, 91, 90, 89, 88, 87, 86, 85, 84, 83, 82, 81

AMEC Environment & Infrastructure **Winnipeg, Manitoba**	LOGGED BY: HWP	COMPLETION DEPTH: 8.7 m
	REVIEWED BY: TG	COMPLETION DATE: 16 December 2013
	Figure No. B1	Page 1 of 1

PROJECT: GWWD Bridges	DRILLED BY: Maple Leaf Drilling Ltd.	BORE HOLE NO: **TH02**
CLIENT: Stantec	DRILL TYPE: Acker MP5 Track Rig	PROJECT NO: WX17312
LOCATION: Anola, Manitoba	DRILL METHOD: 125 mm SSA	ELEVATION: 99.7 m

SAMPLE TYPE	■ Shelby Tube	◿ No Recovery	☒ SPT (N)	▤ Grab Sample	▥ Split-Pen	◧ Core
BACKFILL TYPE	■ Bentonite	⬚ Pea Gravel	▨ Drill Cuttings	⬚ Grout	▥ Slough	⬚ Sand



SOIL DESCRIPTION

SAND (FILL) - gravelly, poorly graded, medium to coarse grained, compact (inferred), frozen, brown

CLAY - silty, trace organics, high plastic, moist, stiff, grey to black

- occasional grey silt lenses below 1.4 m
- mottled brown, occasional sulphate inclusions below 1.5 m
- grey, occasional oxidation below 3.7 m
- trace gravel, occasional silt till inclusions below 4.6 m
- frequent silt till inclusions below 5.3 m
- firm below 5.9 m

SILT (TILL) - trace clay, some sand, some gravel, low plastic, moist, loose, tan

- very dense below 9.1 m

AUGER REFUSAL AT 16.2 m BELOW GRADE IN SUSPECTED VERY DENSE TILL

NOTES:

- Moderate sloughing and seepage was observed below 7.0 m during drilling
- Test hole remained open to 11.6 m below grade with water measured at 4.0 m 10 min after completion
- Test hole backfilled with auger cutting and bentonite

SAMPLE TYPE	SAMPLE NO	SPT (N)
▤	1	
▤	2	
▤	3	
▤	4	
▤	5	
■	6	
▤	7	
▤	8	
■	9	
▤	10	
▤	11	
☒	12	9
▤	13	
☒	14	57
▤	15	
☒	16	74/17
▤	17	
☒	18	50/5.5
▤	19	
☒	20	50/4

COMMENTS

TH Coordinates (UTM):
5524050mN
662706mE

Unconfined Compressive Strength (S6):
Max Stress: 106 kPa
Strain @ Failure: 6.6%
Bulk Density: 1830 kg/m^3
Dry Density: 1284 kg/m^3

Unconfined Compressive Strength (S6):
Max Stress: 95 kPa
Strain @ Failure: 5.1%
Bulk Density: 1900 kg/m^3
Dry Density: 1387 kg/m^3

AMEC Environment & Infrastructure
Winnipeg, Manitoba

LOGGED BY: HWP	COMPLETION DEPTH: 16.2 m
REVIEWED BY: TG	COMPLETION DATE: 16 December 2013
Figure No. B2	Page 1 of 1

17312 GWWD BRIDGE MP22.15.GPJ 14/02/05 03:18 PM (GEOTECHNICAL REVISED)

EXPLANATION OF TERMS AND SYMBOLS

The terms and symbols used on the borehole logs to summarize the results of field investigation and subsequent laboratory testing are described in these pages.

It should be noted that materials, boundaries and conditions have been established only at the borehole locations at the time of investigation and are not necessarily representative of subsurface conditions elsewhere across the site.

TEST DATA

Data obtained during the field investigation and from laboratory testing are shown at the appropriate depth interval.

Abbreviations, graphic symbols, and relevant test method designations are as follows:

*C	Consolidation test	*ST	Swelling test
D_R	Relative density	TV	Torvane shear strength
*k	Permeability coefficient	VS	Vane shear strength
*MA	Mechanical grain size analysis and hydrometer test	w	Natural Moisture Content (ASTM D2216)
		w_l	Liquid limit (ASTM D 423)
N	Standard Penetration Test (CSA A119.1-60)	w_p	Plastic Limit (ASTM D 424)
N_d	Dynamic cone penetration test	E_f	Unit strain at failure
NP	Non plastic soil	γ	Unit weight of soil or rock
pp	Pocket penetrometer strength	γ_d	Dry unit weight of soil or rock
*q	Triaxial compression test	ρ	Density of soil or rock
q_u	Unconfined compressive strength	ρ_d	Dry Density of soil or rock
*SB	Shearbox test	C_u	Undrained shear strength
SO_4	Concentration of water-soluble sulphate	→	Seepage
		▼	Observed water level

* The results of these tests are usually reported separately

Soils are classified and described according to their engineering properties and behaviour.

The soil of each stratum is described using the Unified Soil Classification System[1] modified slightly so that an inorganic clay of "medium plasticity" is recognized.

The modifying adjectives used to define the actual or estimated percentage range by weight of minor components are consistent with the Canadian Foundation Engineering Manual[2].

Relative Density and Consistency:

Cohesionless Soils

Relative Density	SPT (N) Value
Very Loose	0-4
Loose	4-10
Compact	10-30
Dense	30-50
Very Dense	>50

Cohesive Soils

Consistency	Undrained Shear Strength c_u (kPa)	Approximate SPT (N) Value
Very Soft	0-12	0-2
Soft	12-25	2-4
Firm	25-50	4-8
Stiff	50-100	8-15
Very Stiff	100-200	15-30
Hard	>200	>30

Standard Penetration Resistance ("N" value)
The number of blows by a 63.6kg hammer dropped 760 mm to drive a 50 mm diameter open sampler attached to "A" drill rods for a distance of 300 mm after an initial penetration of 150 mm.

---

[1] "Unified Soil Classification System", Technical Memorandum 36-357 prepared by Waterways Experiment Station, Vicksburg, Mississippi, Corps of Engineers, U.S. Army. Vol. 1 March 1953.

[2] "Canadian Foundation Engineering Manual", 3rd Edition, Canadian Geotechnical Society, 1992.

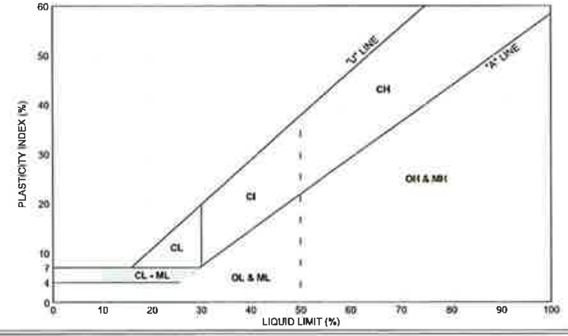
MODIFIED UNIFIED CLASSIFICATION SYSTEM FOR SOILS

MAJOR DIVISIONS			SYMBOLS			TYPICAL DESCRIPTION	LABORATORY CLASSIFICATION CRITERIA
			USCS	GRAPH	COLOUR		
COARSE GRAINED SOILS (MORE THAN HALF BY WEIGHT LARGER THAN 75um)	GRAVELS MORE THAN HALF THE COARSE FRACTION LARGER THAN 4.75mm	CLEAN GRAVELS (TRACE OR NO FINES)	GW	△	RED	WELL GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	$C_u=D_{60}/D_{10} > 4$; $C_c=(D_{30})^2/(D_{10}xD_{60})$ = 1 to 3
			GP	▲	RED	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	NOT MEETING ABOVE REQUIREMENTS
		DIRTY GRAVELS (WITH SOME OR MORE FINES)	GM	▲	YELLOW	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES	ATTERBERG LIMITS BELOW "A" LINE OR PI LESS THAN 4
			GC	▲	YELLOW	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES	ATTERBERG LIMITS ABOVE "A" LINE AND PI MORE THAN 7
	SANDS MORE THAN HALF THE COARSE FRACTION SMALLER THAN 4.75mm	CLEAN SANDS (TRACE OR NO FINES)	SW	⁙	RED	WELL GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	$C_u=D_{60}/D_{10} > 6$; $C_c=(D_{30})^2/(D_{10}xD_{60})$ = 1 to 3
			SP		RED	POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	NOT MEETING ABOVE REQUIREMENTS
		DIRTY SANDS (WITH SOME OR MORE FINES)	SM	▥	YELLOW	SILTY SANDS, SAND-SILT MIXTURES	ATTERBERG LIMITS BELOW "A" LINE OR PI LESS THAN 4
			SC	▨	YELLOW	CLAYEY SANDS, SAND-CLAY MIXTURES	ATTERBERG LIMITS ABOVE "A" LINE AND PI MORE THAN 7
FINE-GRAINED SOILS (MORE THAN HALF BY WEIGHT SMALLER THAN 75um)	SILTS BELOW "A" LINE NEGLIGIBLE ORGANIC CONTENT	$W_L < 50\%$	ML	▥	GREEN	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY SANDS OF SLIGHT PLASTICITY	CLASSIFICATION IS BASED UPON PLASTICITY CHART (SEE BELOW)
		$W_L > 50\%$	MH	▥	BLUE	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS, FINE SAND OR SILTY SOILS	
	CLAYS ABOVE "A" LINE NEGLIGIBLE ORGANIC CONTENT	$W_L < 30\%$	CL	▨	GREEN	INORGANIC CLAYS OF LOW PLASTICITY, GRAVELLY, SANDY OR SILTY CLAYS, LEAN CLAYS	
		$30\% < W_L < 50\%$	CI	▨	GREEN-BLUE	INORGANIC CLAYS OF MEDIUM PLASTICITY, SILTY CLAYS	
		$W_L > 50\%$	CH	▨	BLUE	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS	
	ORGANIC SILTS & CLAYS BELOW "A" LINE	$W_L < 50\%$	OL	▥	GREEN	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY	WHENEVER THE NATURE OF THE FINES CONTENT HAS NOT BEEN DETERMINED, IT IS DESIGNATED BY THE LETTER "F", E.G. SF IS A MIXTURE OF SAND WITH SILT OR CLAY
		$W_L > 50\%$	OH	▨	BLUE	ORGANIC CLAYS OF HIGH PLASTICITY	
HIGHLY ORGANIC SOILS			PT	〰	ORANGE	PEAT AND OTHER HIGHLY ORGANIC SOILS	STRONG COLOUR OR ODOUR, AND OFTEN FIBROUS TEXTURE

SPECIAL SYMBOLS

LIMESTONE	▦	OILSAND	○
SANDSTONE		SHALE	☰
SILTSTONE	⁚	FILL (UNDIFFERENTIATED)	▩

PLASTICITY CHART FOR SOILS PASSING 425μm SIEVE



SOIL COMPONENTS

FRACTION	U.S. STANDARD METRIC SIEVE SIZE	
	PASSING	RETAINED
GRAVEL		
COARSE	76mm	19mm
FINE	19mm	4.75mm
SAND		
COARSE	4.75mm	2.00mm
MEDIUM	2.00mm	425μm
FINE	425μm	75μm
FINES (SILT OR CLAY BASED ON PLASTICITY)	75μm	

DEFINING RANGES OF PERCENT BY WEIGHT OF MINOR COMPONENTS	
PERCENT	DESCRIPTOR
35 - 50	AND
30 - 35	Y / EY
10 - 20	SOME
1 - 10	TRACE

NOTES:

1. ALL SIEVE SIZES MENTIONED ARE U.S. STANDARD ASTM E.11.
2. COARSE GRAINED SOILS WITH TRACE TO SOME FINES GIVEN COMBINED GROUP SYMBOLS, E.G. GW-GC IS A WELL GRADED GRAVEL SAND MIXTURE WITH TRACE TO SOME CLAY.
3. DUAL SYMBOLS ARE USED TO INDICATE BORDERLINE SOIL CLASSIFICATIONS.

OVERSIZED MATERIAL

ROUNDED OR SUBROUNDED:

COBBLES 76mm to 200mm
BOULDERS > 200mm

NOT ROUNDED:

ROCK FRAGMENTS ? 76mm
ROCKS > 0.76 CUBIC METRE IN VOLUME

AMEC Environment & Infrastructure
a Division of AMEC Americas Limited

amec

FINAL REPORT
GEOTECHNICAL INVESTIGATION
GREATER WINNIPEG WATER DISTRICT
RAILWAY BRIDGE MILE 41.3
RM OF SPRINGFIELD, MANITOBA

Submitted to:

Stantec Consulting Ltd.

100 – 1355 Taylor Avenue
Winnipeg, Manitoba
R3C 3Y9

Submitted by:

AMEC Environment & Infrastructure
A Division of AMEC Americas Limited

440 Dovercourt Drive
Winnipeg, Manitoba
R3Y 1N4
Office: (204) 488-2997
Fax: (204) 489-8261

5 February 2014

WX17312

TABLE OF CONTENTS

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LIST OF APPENDICES

1.0 INTRODUCTION

At the request and authorization of Mr. Mike Boissonneault, P.Eng., Project Manager, and Senior Associate for Stantec Consulting Ltd (Stantec), AMEC Environment & Infrastructure, a division of AMEC Americas Limited (AMEC), completed a geotechnical investigation for the proposed replacement of the Greater Winnipeg Water District (GWWD) railway bridge located at Mile 41.3 in the RM of Springfield, Manitoba. The purpose of the geotechnical investigation was to verify the subsurface soil and groundwater conditions at the site in order to provide geotechnical recommendations for foundation design and construction. The scope of work for the project was outlined in AMEC's proposal number WPG2013.557, dated 3 December 2013. The geotechnical investigation was completed under subcontract to Stantec, Stantec Project Number and Subconsultant Agreement 113732050.

This report summarizes the field and laboratory testing programs, describes the subsurface conditions encountered at the test hole locations, and presents geotechnical engineering recommendations for: driven steel pile foundation alternatives; frost design considerations; abutment backfill and lateral earth pressures; and foundation concrete. Slope stability analyses, embankment settlement analyses, and pore pressure and fill staging analyses were not part of the scope of work for this geotechnical investigation. AMEC has assumed that these analyses are being undertaken by others as required for design.

2.0 SITE AND PROJECT DESCRIPTION

2.1 Site Description

The GWWD Mile 41.3 site is located within the RM of Springfield, near the intersection of Forestry Road and Road 32E. Specifically, the site is located about 560 m west of Centerline Road, where the GWWD Rail Line crosses Cook's Creek.

At Mile 41.3, the GWWD rail line consists of a single track. Currently the crossing consists of a double span wooden bridge, supported on timber piles. Head walls at the abutments consisted of wooden lagging supported by steel piles. Installation depths, for both the wooden foundation piles and steel abutment piles, as well as sizing details, were not known. Rip-rap appeared to have been placed on both sides of the crossing, both under the bridge and extending out from the bridge on both sides. The thickness, material type, total quantity, and total coverage area of the rip-rap could not be determined due to snow cover.

Cook's Creek is oriented relatively perpendicular to the existing bridge structure. Drainage ditches providing drainage into Cook's Creek were present along both sides of the rail embankment. Generally, the site is surrounded by flat-lying farm fields, with the rail track elevated about 2 to 3 m above the surrounding fields. The elevated berm on which the rail track is located extended beyond the bridge site on both sides of the crossing. To the east of the rail bridge, Road 32E crosses the rail line at an at-grade crossing.

At the time of the geotechnical investigation, the farm fields surrounding the site, as well as the rail embankment, were covered by snow. Access to the site was gained via the rail line, which had been closed to rail traffic by the City of Winnipeg at the request of Stantec in order to provide a safe work area for drilling.

2.2 Proposed Development

AMEC understood that the proposed development at Mile 41.3 consists of a full replacement of the existing wooden bridge. Exact details of the proposed bridge were not known, however AMEC understood that the new structure will be a single span structure of approximately equal size to the existing structure and that abutment locations would not change significantly from their current location. Based on information provided by Stantec, AMEC understood that steel HP310x110 piles are the preferred foundation type. Foundation loads were not available at the time of this report.

3.0 GEOTECHNICAL INVESTIGATION PROGRAM

Prior to initiating drilling, AMEC notified public utility providers (i.e. Manitoba Hydro, MTS, City of Winnipeg, etc.) of the intent to drill in order to clear public utilities, and where required, met with said representatives on-site.

On 17 December 2013, AMEC supervised the drilling of two test holes (TH01 and TH02) at the approximate locations illustrated in Figure 1. The test holes were drilled using an Acker MP5 track mounted drill rig equipped with 125 mm diameter solid stem and 175 mm diameter hollow stem augers; operated by Maple Leaf Drilling Ltd. of Winnipeg, Manitoba.

During drilling, AMEC field personnel visually classified the soil stratigraphy within the test holes in accordance with the Modified Unified Soil Classification System (MUSCS); as well as noted any observed seepage and/or sloughing conditions. Grab samples were collected at selected depths and retained in sealed plastic bags for shipping, review, and select testing in AMEC's Winnipeg laboratory. Shelby tube samples were also collected at selected depths for possible laboratory testing. The in-situ relative consistency of cohesive overburden was evaluated during drilling using pocket penetrometer readings. The recorded pocket penetrometer readings are shown on the test hole log. The relative consistency of sand and of the underlying till was evaluated using standard penetration tests (SPTs), where the number of blows to drive the SPT sampler 0.3 m into the soil was recorded. The recorded number of blows is shown on the test hole logs as the SPT (N) value.

Upon completion of drilling, the depth to slough and groundwater level within each test hole was obtained after an elapsed time of about 10 minutes. Subsequently, the test holes were backfilled to grade with bentonite and auger cuttings. Excess auger cuttings were left neatly on site. UTM coordinates of the test hole locations were obtained using a hand held Garmin GPS, and are summarized in Table 3-1.

Table 3-1: Testhole Coordinates (UTM)

Testhole ID	Northing	Easting	Local Elevation[1] (m)
TH01	5516021.5	690232.9	~ 99.7
TH02	5516028.5	690256.9	~ 99.7

1. Local elevation 100 m equals approximate top of track

Following completion of the field drilling program, a laboratory testing program was conducted on selected soil samples obtained from the test holes. The laboratory testing program consisted of moisture content determinations, and one set of liquid limit and plastic limit determinations.

Detailed test hole logs summarizing the sampling, field testing, laboratory test results, and subsurface conditions encountered at the test hole locations are presented in Appendix A. Actual depths noted on the test hole logs may vary by ± 0.3 m from those recorded due to the method by which the soil cuttings are returned to the surface. Summaries of the terms and symbols used on the test hole logs and of the Modified Unified Soil Classification System are also presented in Appendix A.

4.0 SUBSURFACE CONDITIONS

4.1 Stratigraphy

Consistent with the regional geology and anticipated conditions, the stratigraphy at the test hole location consisted of the following, in descending order from grade level:

- Sand and Gravel Fill
- Sand or Clay
- Silt (Till)

A brief description of each of the soil layers bulleted above is presented below: For detailed descriptions, the test hole logs in Appendix A should be consulted.

Sand and Gravel Fill

Sand and gravel fill was encountered at the surface of both test holes, and extended to about 3.1 m below grade at TH01 and about 1.5 m below grade at TH02. The fill was generally described as poorly graded, medium to coarse grained, frozen, and brown. In-situ moisture contents completed on a total of six thawed samples from both boreholes ranged from about 3 percent to 6 percent.

Significant sloughing of the sand and gravel fill layer was noted in TH01, and necessitated a switch from solid stem auger to hollow stem auger drilling beyond 4.6 m below grade to control slough into the open bore. Solid stem auger drilling was not attempted at TH02, which was immediately drilled with hollow stem from grade.

Sand

Sand was encountered beneath the sand and gravel fill at TH02 and extended to about 4.6 m below surface. The sand was generally described as poorly graded, fine to medium grained with trace fines becoming silty with some clay below about 3.1 m, moist becoming wet below about 3.1 m, and grey. SPT N value of 22 blows and 11 blows were obtained within the layer at about 1.5 m and 3.1 m below grade, respectively, indicative of compact relative density. In-situ moisture content results within the layer ranged from about 4 percent within the clean sand at the top of the layer to about 30 percent within the wet silty sand below 4.6 m.

Clay

Clay was encountered beneath the sand and gravel fill at TH01 and extended to about 4.6 m below surface. The clay was silty with trace organics and rootlets, high plastic, moist, firm becoming stiff below 3.6 m, and dark grey. In-situ moisture contents of about 38 percent and 30 percent were obtained on two samples obtained at about 3.5 m below grade and 4.5 m below grade, respectively.

Although not observed in TH02, it is advised that a thin layer of clay (i.e. less than 1.5 m thick) could have gone unnoticed due to the Hollow Stem Auger technique employed, and in this regard, may exist above the silt till at TH02.

Silt(Till)

Glacial silt till was encountered beneath the clay in TH01 and the sand at TH02 at about 4.6 m below grade, and extended to the test hole termination depth (defined by practical SPT refusal) of 8.1 m at both test holes. The till comprised a low to non plastic silt matrix containing some sand, some gravel, trace clay, and was moist to damp. In-situ moisture contents within the till ranged from about 16 percent to about 8 percent. Atterberg Limits testing on a sample of the silt collected at about 8.0 m below grade indicated a liquid limit of about 17 percent, and a plastic limit of about 9 percent.

SPT 'N' values ranged from 23 at the top of the till in TH02 to in excess of 50 blows per foot at all other locations, suggesting dense to very dense conditions.

4.2 Groundwater and Sloughing Conditions

Seepage and sloughing conditions were noted during drilling, and the depths to the accumulated water levels within the test holes were measured about ten minutes after drilling.

Sloughing of the sand and gravel was noted during solid stem auger drilling at TH01, and eventually necessitated a switch in drilling technique from solid stem augers to hollow stem auger to control slough into the open bore. Hollow stem auger drilling from grade at TH02 prevented sloughing of the sand and gravel fill.

Slight seepage within TH01 was observed between grade and 3.7 m below grade, as well as between 4.6 m and 8.1 m below grade. Similarly, seepage was observed in TH02 below 1.5 m below grade after the augers were removed.

Upon completion of drilling and removal of the hollow stem augers, the test holes remained open to between 6.4 m and 6.7 m below grade. The depth to accumulated water was measured at 5.8 m below grade within both boreholes.

Seepage water within both boreholes is considered likely as originating as perched groundwater within the upper sand and sand fill, as well as groundwater originating from thin sand stringers within the till that went undetected as a result of the hollow stem auger and rotary drill technique. For design purposes per the recommendations outlined in this report, a groundwater table of 3.3 m below top of track (i.e. local elevation 96.7 m) is recommended. It should be noted that only short-term seepage and sloughing conditions were observed and that groundwater levels can fluctuate annually, seasonally or as a result of construction activity.

5.0 GEOTECHNICAL RECOMMENDATIONS

5.1 General Evaluation

The stratigraphy and soil conditions encountered within the test holes advanced at the site is considered typical of conditions within the region and are considered favourable for the proposed development.

From a foundations perspective, soil conditions are considered suitable for the use of the driven steel H-piles indicated as preferred by Stantec. Driven steel pipe piles are also regarded as a suitable pile foundation alternative. Other suitable pile alternatives included bored concrete piles bearing within the underlying silt till; however, bored piles would necessitate casing through the sand fill and clay to control potential slough conditions. Given Stantec's indicated preference for driven Steel H-Piles, foundation recommendations here-in are limited to driven steel HP and pipe piles. Recommendations for other foundation alternatives can be provided upon request.

The following sections provide discussion and recommendations as they pertain to: driven steel piles; lateral earth pressures on below grade walls; frost design considerations; and foundation concrete.

5.2 Driven Steel Pile Foundations

As previously discussed, soil conditions at the site are considered suitable for the use of the driven steel H-piles indicated as preferred by Stantec, as well as pipe piles. Notwithstanding, the following conditions should be considered in final selection and design of piles:

- The underlying silt till at the site below 6 m is very dense and depending on selection of the pile type (i.e. H-Pile, open-ended, or closed-ended pipe), end bearing development could vary with pile type and location. H-piles are anticipated to penetrate deeper than open ended or closed ended pipe piles.
- High end-bearing development within the silt till could inhibit pile penetration local elevation 94 m (i.e. beyond 6 m below test hole elevation) and the achievable

embedment depth for tensile (uplift) resistance to transient uplift loads and frost. In this regard, pile type selection and sizing must consider both the compressive and tensile requirements of the pile, and the ability to both achieve the required compressive capacity and achieve the minimum embedment depth required for uplift resistance.

AMEC understands that the foundation will be designed in accordance with the 2013 AREMA Manual for Railway Engineering. AMEC's interpretation of recommended practices outline in the manual is that foundation design employs allowable stress design (ASD) principles as opposed to Limit State or Load-Factor Resistance Design (LFRD) design principles. In this regard, parameters here-in have been presented for use in ASD. If parameters for alternative design principles (i.e. Limit States) are required, this office should be contacted for revisions.

5.2.1 Axial Compressive Resistance of Single Driven Steel Piles

The 'allowable' compressive resistance of a driven steel pile (H or pipe) as a function of embedment depth may be determined using the 'allowable' unit shaft friction and unit end bearing pressures recommended in Table 5-1.

Table 5-1: 'Allowable' Unit Shaft Friction & End Bearing Values for Driven Steel Piles

Elevation Range (m)	Assumed Average Soil Type	Shaft Friction (kPa)	End Bearing (kPa)
99.7 to X[2]	Sand Fill	Linearly increasing with depth from: 0 to 12	--*
X to 95.1	Sand or Clay	12	--*
95.1 to 93.7	Silt Till	24	560
93.7 to 91.6 m	Silt Till	48	1,800

[1] The elevations presented assume top of track to be approximate local elevation 100.0 m.

[2] X = the elevation of the frost penetration front at the pile interface, determined in accordance with the recommended frost penetration depth presented in Section 5.4, to account for possible movement of the soil away from the perimeter of the pile.

The above 'allowable' unit shaft friction and 'allowable' unit end bearing values include a factor of safety of 2.5.

For all pipe pile types and sizes, shaft friction should only be applied to the exterior surface area of the pile. In the case of steel H piles, shaft friction may be applied to the exterior sides of the two flanges plus twice the depth of the web (i.e. the box perimeter). For pipe piles with a closed-end configuration, end bearing may be applied to the full cross-sectional area of the toe of the pile. For H-piles and open end pile configurations, the area over which end bearing may be applied varies with the pile diameter. For small diameter pipes piles (i.e. DN300 or smaller) and H-Piles, there is considered a higher potential for 'plugging' of the pile during installation, and as such, it is considered acceptable to apply the end bearing to the full cross-sectional area of the toe of the pile which may be taken as the area enclosed by the outer circumference of a pipe section, or the cross sectional area of a rectangle bounded by the flanges in the case of steel H sections. For larger pile sizes, 'plugging' of the pile during driving may be variable, and the end bearing values provided above should be re-evaluated by AMEC for large diameter piles. However, for current design purposes, the unit end bearing values outlined above may be applied to the steel area of the toe of piles larger than DN300. If during construction driving resistance is lower or higher than anticipated, 'soil plug' development and end bearing development may be quantified via dynamic pile testing by pile driving analyzer (PDA Testing) and CAPWAP1 analysis.

Due to limitations on the driveability of the pile imposed by the yield strength of the pile, as a guide to initial design and selection of pile wall thickness and steel grade, it is recommended that the maximum design 'allowable' compressive resistance of a steel pile be limited to 0.25FyAs (i.e. a fraction of the unfactored structural yield capacity of the pile), where: fy is the nominal yield stress of the steel, and As is the cross-sectional area of steel in the pile. The purpose of this restriction is to mitigate the risk of statically designing a pile that cannot be driven with enough energy or force to overcome dynamic soil resistance and subsequently develop the design static load resistance without yielding or damaging the pile. Subject to driveability analysis and evaluation of driving stresses at the pile design stage, the maximum 'allowable' compressive stress could be increased to as much as 0.35FyAs.

Additional comments for design and construction of driven steel piles are as follows:

- Static pile design parameters pertain to soil resistance only. The pile cross sections must be designed to withstand the design loads and the driving forces during installation.
- Although not commonly employed for the installation of driven piles, if a pre-bore was required (i.e. for ground disturbance clearance or contractor preference), shaft friction must be neglected over the depth of the pre-bore.
- Piles must be spaced a minimum of three pile diameters apart, as measured from centre-to-centre, in order to act individually as single piles in vertical compression when used in a small pile group of three piles or less. Where pile groups larger than 3 piles are required, the pile group should be reviewed by AMEC.
- Once the pile configuration is known, AMEC recommends that a driveability analysis (i.e. WEAP) be completed prior to proceeding to construction, and concurrent with selection of the pile driving equipment, to confirm the ability of the hammer and appurtenances to drive the piles to the design capacity and embedment depth without damage. Similarly, the driveability analysis can be extended to develop termination criteria for use in pile installation monitoring. It should be noted that driveability analyses should be completed using ultimate soil parameters.
- All piles driven within five pile diameters should be monitored for heave and, where heave is observed, piles should be re-driven. Piles that are re-driven should be advanced to at least the original elevation.
- All piles should be driven continuously to practical refusal once driving is initiated.

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[1] PDA : Pile Driving Analyzer, CAPWAP: software to analyze PDA Test data

- Any piles that have been damaged, are excessively out of plumb, or have refused prematurely may need to be replaced, pending a review by a qualified geotechnical engineer of their load carrying capability and estimated settlement.
- All pile caps and grade beams should be underlain by a minimum 150 mm thick void form to accommodate the expansive nature and potential frost heave of the underlying soil.
- Prior to the pile installation, the piles should be inspected to confirm that the material specifications are satisfied. As a minimum, steel H-piles should meet the requirements of CAN/CSA-G40.20/G40.21, Grade 350 W, and pipe piles should have a minimum yield strength of 310 MPa (i.e. ASTM A252 Grade 3 steel). The piles should be free from protrusions, which could create voids in the soil around the pile during driving.
- Monitoring of the pile installation by an experienced inspector is recommended to verify that the piles are installed in accordance with design assumptions and the driving criteria are satisfied. For each pile, a complete driving record in terms of the number of blows per 300 mm of penetration should be recorded by the inspector and reviewed during pile installation by the designer.

5.2.2 Tensile (Uplift) Resistance (Single Pile)

In the case of driven steel piles, the uplift resistance of a single pile will be provided by the sustained downward load on the pile (if applicable) and shaft friction along the length of pile embedded below the depth of frost penetration. In the case of straight shaft (i.e. driven steel) piles, the soil component of the 'allowable' uplift resistance to *sustained* tensile loads will be provided by shaft friction and can be determined using 70% of the shaft friction values outlined in Table 5-1. For pipe piles, only the exterior surface area of the pile in contact with the soil should be used in the calculation of the frictional resistance. In the case of steel H piles, the surface area should include the exterior sides of the two flanges plus twice the depth of the web. For frost and *transient* uplift loads, such as those due to wind gusts, no reduction of the shaft friction values in Table 5-1 is required. Transient loads would not be additive to the uplift forces due to frost action.

Although not commonly employed for the installation of driven steel piles, if a pre-bore was required (i.e. for ground disturbance clearance or contractor preference), shaft friction must be neglected over the depth of the pre-bore.

5.2.3 Lateral Resistance (Single Pile)

Piles resist laterally applied loads by deflecting until the necessary resistance is mobilized in the adjacent soils. The majority of lateral load resistance for slender piles is generally provided within the upper 4 to 5 m of the soil profile (i.e. the typical point of inflection for the pile). The maximum bending moment typically occurs at 1.5 m to 3.0 m below grade depending on the applied loading and soil resistance. The allowable lateral capacity depends upon the properties of the soil and pile material, pile sizes, fixity of the top of the pile, depth of embedment, height of load application above ground, vertical load applied and tolerable deflections.

Where the lateral load capacities or magnitude of movements of piles are critical, it is recommended that the lateral deflections and design capacities of piles or groups of piles be evaluated using Reese's method of p-y curves. This method models the strength-deformation characteristics using load-displacement curves for the various soil strata, and the non-linear behaviour of the soil. With the method of p-y curves, solutions may be obtained through an iterative procedure performed using LPILE Software for single piles, and extended to pile groups by using GROUP Software to analyze the behaviour of piles in a group subjected to both axial and lateral loadings. The analytical procedure provides lateral pile deflections, generated bending moments, shear forces, and the soil reaction computed at close intervals over the depth of the pile.

Based on conditions observed within the appended test hole logs, the stratigraphy and soil parameters outlined in Table 5-2 are considered suitably representative of the average subsurface conditions expected to influence the lateral behaviour of driven steel piles at the Site. Clay has conservatively been assumed above the till between 3.1 m and 4.6 m below grade.

Table 5-2: LPile Input Parameters

Elevation Range (m)[1]	**Soil Type**	**Effective Unit Weight (kN/m^3)**[2]	**Friction Angle (•)**	**Cohesion (kPa)**	**E50 (%)**	**p-y subgrade modulus, k (kPa/m)**
100.0 to 96.7	Sand Fill	20	28	0	n/a	Default
96.7 to 95.1	Clay	9	n/a	50	0.015	Default
95.1 to 91.6	Silt Till	10	35	0	n/a	Default

[1] The elevations presented assume top of track to be approximate local elevation 100.0 m.
[2] Groundwater level of 3.3 m below top of track was assumed.

The use of zero lateral resistance or skin friction in the upper part of the pile for sandy soils has not been recommended because the sand is cohesionless and therefore a permanent gap between the pile and the soil due to installation or frost effects is not expected.

Lateral pile analysis of a prescribed pile configuration was not part AMEC's scope of work for this investigation. Notwithstanding, lateral pile analysis could be conducted by AMEC for specified pile configurations on request.

5.2.4 Single Pile Settlement

The settlement of a single pile depends on the applied load, strength-deformation properties of the foundation soils, load transfer mechanism, load distribution over the pile embedment depth, and the relative proportions of the load carried by shaft friction and end-bearing. Assuming good workmanship, inclusive of good excavation, the predicted settlement of piles at working loads equal to a maximum given by the 'allowable' pile capacity are 0.5 to 1 percent of the shaft diameter plus the elastic shortening of the pile due to the compressive load acting on the pile.

5.2.5 Pile Group Effects

Generally, piles will behave individually in compression (i.e. group efficiency equals 1.0) when a minimum centre-to-centre spacing of 5 pile diameters is provided between adjacent piles, and will behave individually laterally when the center-to-center spacing is greater than 3 diameters in the direction transverse to loading (side-by-side), and greater than 8 diameters in the direction parallel to loading (in-line). However, for circumstances in which piles are closely spaced and/or the piles are connected by a rigid pile cap forcing equal settlement behaviour at the pile heads, interaction between the piles will occur and should be considered in design.

Notwithstanding the above, AMEC does not anticipate that large groups of four or more closely spaced piles will be required. Consequently, recommendations pertaining to the axial and lateral load resistances of pile groups are not provided here-in. If pile groups are required by design, AMEC should be notified and a review of possible group interactions effects evaluated.

5.3 Lateral Earth Pressures on Below Grade Walls (i.e. Wing Walls)

5.3.1 Soil Design Parameters

Below grade walls (i.e. wing walls) will be required to resist lateral pressures from the surrounding soil, water, and any additional surcharge loading (i.e. fill, live surface loads, etc.). Table provides recommended design values for the bulk unit weight, angle of internal friction, and 'at rest', active, and lateral earth pressure coefficients for moderately to well compacted native sand and compacted granular fill soils.

Table 5-3: Earth Pressure Coefficients and Soil Unit Weights

Soil Type		Active Pressure Coefficient K_a	"At Rest" Earth Pressure Coefficient K_o	Passive Pressure Coefficient[a] K_p	Total Soil Unit Weight (kN/m^3)	Friction Angle (deg) Between Soil and Concrete
Gravel Fill	Well Compacted	0.25	0.40	2.67	23	25
	Moderately Compacted	0.30	0.47	2.17	22	21
Sand Fill	Well Compacted	0.30	0.47	2.17	21	21
	Moderately Compacted	0.36	0.53	1.85	20	18

The passive earth pressure coefficients provided in Table 5-3 include a reduction factor of 1.5 to account for the partial mobilization of passive resistance that is consistent with the small wall displacements expected under operational conditions. Relatively large wall displacements would be necessary to realize full passive resistances.

With respect to subsurface drainage and groundwater conditions over the depth of the foundation structure, the phreatic surface at the site should be taken as 3 m below existing grade. The use of free draining backfill and the provision of drainage behind vertical subsurface walls is strongly recommended, and will further serve to mitigate frost action on vertical walls extending through the zone of frost penetration.

The magnitude and distribution of the lateral earth pressures on below grade structures will depend on such factors as the rigidity of the below grade structure; the degree of compaction of the backfill against the structure; the backfill soil type; the slope angle at the structure/soil interface; and the subsurface drainage and groundwater conditions over the height of the structure. It is anticipated that a sloped excavation will be implemented for construction of below grade foundation structures, which will necessitate the placement of backfill behind below grade structure walls. The magnitude and distribution of the lateral earth pressures (P) on below grade structures will depend on the degree of compaction of the backfill. In addition to earth pressures, lateral stresses generated by any applicable surcharge loads also need to be evaluated in the design. Recommended earth pressure distributions for light to moderate and moderate to well compacted backfill cases, as well as for line or point surcharge loads, are discussed in Section 5.3.2.

5.3.2 Calculation of Earth Pressure Distributions and Load Factors

5.3.2.1. Moderate to Well Compacted Backfill Case

Where subgrade support on the surface of the retained soil behind a wall is required, as it is for headwalls, the backfill against the wall will need to be compacted to at least 95 percent Standard Proctor maximum dry density. The use of free draining backfill behind below grade structures is strongly recommended in order to maintain drained conditions behind the structure. Assuming drained conditions, the design earth pressure distribution should adopt a combined trapezoidal/triangular distribution as shown on Figure 2 to account for the induced lateral pressures due to compaction. Figure 2 also provides the relationships to be used in the calculation of the compaction induced earth pressures, and tabulated loads (P) generated by typical compactors. The earth pressure coefficients to be used in the calculation of the lateral pressures should be those applicable to the backfill types given in Table above.

If sub-drainage is not provided and it is possible by design for a perched groundwater to develop within the retained soil (i.e. “bathtub” effect associated with gravel fill soils surrounded by low permeable fine grained soil types), the hydrostatic component should be included in addition to the earth pressure given in Figure 2.

5.3.2.2. Surcharge Loads

In addition to earth pressures, lateral stresses generated by surcharge loads, such as point loads from locomotives, also need to be evaluated in the design. For line or point surcharge loads, the lateral pressures should be determined using the relationships given in Figure 4. In the case of uniformly distributed surcharge loads, such as those acting on the surface of the retained soil, the induced lateral earth pressure may be determined by multiplying the surcharge load by the appropriate earth pressure coefficient.

5.4 Frost Design Considerations

5.4.1 Frost Penetration Depth

The upper stratigraphy at the test hole locations, and across the site, is considered moderately to highly frost susceptible in the presence of water, and as such, frost effects should be considered for foundations or surface structures sensitive to movement. Based on historical temperature data for the area, a design frost penetration of 2.4 m below final grade is recommended in unheated areas that will not have regular snow or vegetative ground cover. It should be noted that this recommended frost penetration depth extends both vertically and laterally behind final surface (i.e. extends 2.4 m behind the headwall).

5.4.2 Pile Foundations

Frost forces applied to pile foundations include adfreeze pressures acting along the pile shafts within the depth of frost penetration. If pile caps are used and extend beyond the perimeter of the underlying pile, then frost heave forces acting on the undersides of the pile caps, as well as any connecting supports (i.e. lateral tie between the piles) will also need to be considered.

5.4.2.1. Frost Heave

To reduce the potential of frost heave pressures, a void-forming product should be installed beneath the underside of the pile caps and any other structural element located within the depth of frost penetration above the groundwater table. The recommended minimum thickness of the void should be 150 mm. Alternatively, a compressible material may be used in lieu of a void forming material, and the uplift pressures may be taken as the crushing strength of the compressible medium. It is recommended that a frost heave of 150 mm be assumed in determining the required thickness for the void-filler and the associated uplift pressures associated with the thickness used.

The finished grade adjacent to each pile cap should be capped with well compacted clay and sloped away so that the surface runoff is not allowed to infiltrate and collect in the void space or in the compressible medium.

The use of void-forming product below the groundwater is unfeasible. In instances where groundwater is located within the recommended depth of frost penetration, the underside of foundation elements such as pile caps should extend below the depth of frost penetration to mitigate frost heave development on the underside of the foundation element.

5.4.2.2. Adfreeze Stresses

Resistance to adfreeze and frost heave forces will be provided by the sustained vertical loads on the foundation, the buoyant weight of the foundation and dead weight of the structure, and the soil uplift resistance component provided by the length of the pile extending below the depth of frost penetration. In the case of straight shaft (i.e. driven steel) piles, the adfreeze force acting on the pile may be determined assuming an unfactored unit adfreeze stress of 65 kPa applied to the exterior surface of the pile and supported foundation elements (i.e. pile caps) located within the zone of frost penetration. The uplift resistance of the pile below the depth of frost may be determined using the Tensile (Uplift) Resistance recommendations presented in Section 5.2.2.

5.5 Foundation Concrete

Where concrete elements outlined in this report and all other concrete in contact with the local soil will be subjected in service to weathering, sulphate attack, a corrosive environment, or saturated conditions, the concrete should be designed, specified, and constructed in accordance with concrete exposure classifications outlined in the latest edition of CSA standard A23.1, Concrete Materials and Methods of Concrete Construction. In addition, all concrete must be supplied in accordance with current Manitoba and National Building Code requirements.

Based on significant data gathered through previous work in Southern Manitoba, water soluble sulphate concentrations in the soil are typically in the range of 0.2% to 2.0%. As such, the degree of sulphate exposure at the site may be considered as ‘severe’ in accordance with current CSA standards, and the use of sulphate resistance cement (Type HS or HSb) is recommended for concrete in contact with the local soil. Furthermore, air entrainment should be incorporated into any concrete elements that are exposed to freeze-thaw to enhance its durability.

It should be recognized that there may be structural and other considerations, which may necessitate additional requirements for subsurface concrete mix design.

5.6 Construction Monitoring and Testing

All engineering design recommendations presented in this report are based on the assumption that an adequate level of testing and monitoring will be provided during construction and that all construction will be carried out by a suitably qualified contractor experienced in foundation and earthworks construction. An adequate level of testing and monitoring is considered to be:

• for earthworks:	full-time monitoring and compaction testing.
• for deep foundations:	design review and full time monitoring during construction.
• for concrete construction:	testing of plastic and hardened concrete in accordance with the latest editions of CSA A23.1 and A23.2; and review of concrete supplier’s mix designs for conformance with prescribed and/or performance concrete specifications.

AMEC requests the opportunity to review the design drawings, and the installation of the foundations, to confirm that the geotechnical recommendations have been correctly interpreted. AMEC would be pleased to provide any further information that may be needed during design and to advise on the geotechnical aspects of specifications for inclusion in contract documents.

6.0 CLOSURE

The findings and recommendations presented in this report were based on geotechnical evaluation of the subsurface conditions observed during the site investigation described in this report. If conditions other than those reported in this report are noted during subsequent phases of the project, or if the assumptions stated herein are not in keeping with the design, this office should be notified immediately in order that the recommendations can be verified and revised as required. Recommendations presented herein may not be valid if an adequate level of inspection is not provided during construction, or if relevant building code requirements are not met.

Soil conditions, by their nature, can be highly variable across a site. The placement of fill and prior construction activities on a site can contribute to the variability especially in near surface soil conditions. A contingency should always be included in any construction budget to allow for the possibility of variation in soil conditions, which may result in modification of the design and construction procedures.

This report has been prepared for the exclusive use of Stantec Consulting Ltd., and their agents, for specific application to the project described in this report. The data and recommendations provided herein should not be used for any other purpose, or by any other parties, without review and written advice from AMEC. Any use that a third party makes of this report, or any reliance or decisions made based on this report, are the responsibility of those parties. AMEC accepts no responsibility for damages suffered by a third party as a result of decisions made or actions based on this report.

This report has been prepared in accordance with generally accepted soil and foundation engineering practices. No other warranty, either expressed or implied, is made.

Respectfully submitted,
AMEC Environment & Infrastructure,
A Division of AMEC Americas Limited

PROVINCE OF MANITOBA
5 Feb 2014
K. W.
JOHNSON
Member
24333
REGISTERED PROFESSIONAL ENGINEER

APEGM
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AMEC Environment & Infrastructure, a Division of AMEC Americas Limited
No. 555 Date: 5 Feb 2014

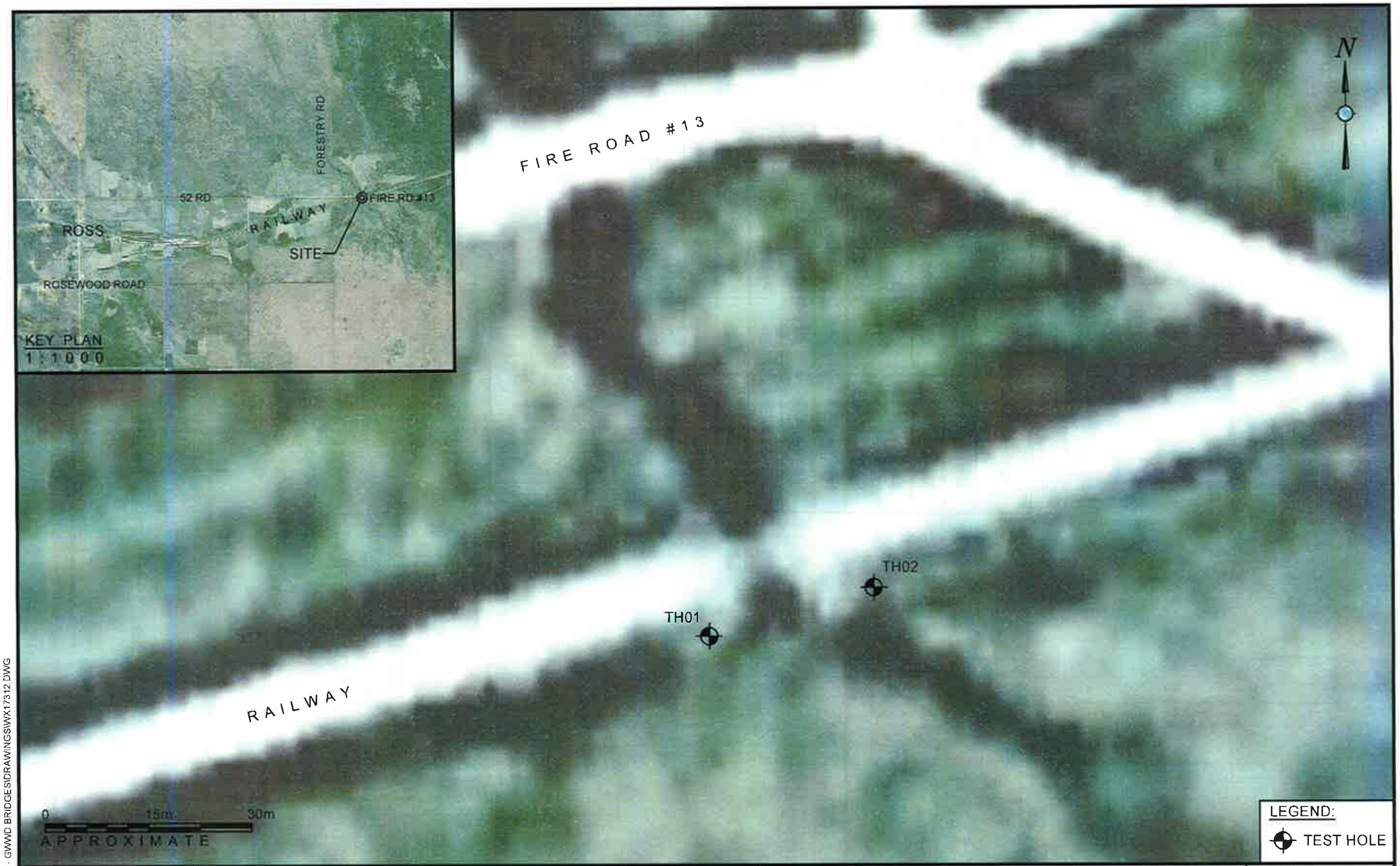
Kelly Johnson

Kelly Johnson, P. Eng.
Senior Geotechnical Engineer

Reviewed by:

Harley Pankratz, P.Eng.
Vice President, Eastern Prairies/Northern Alberta

FIGURES



CLIENT LOGO

CLIENT

STANTEC CONSULTING LTD.

AMEC Environment & Infrastructure
440 DOVERCOURT DRIVE
WINNIPEG, MANITOBA R3Y 1N4
PHONE: 204.488.2997 FAX 204.489.8261

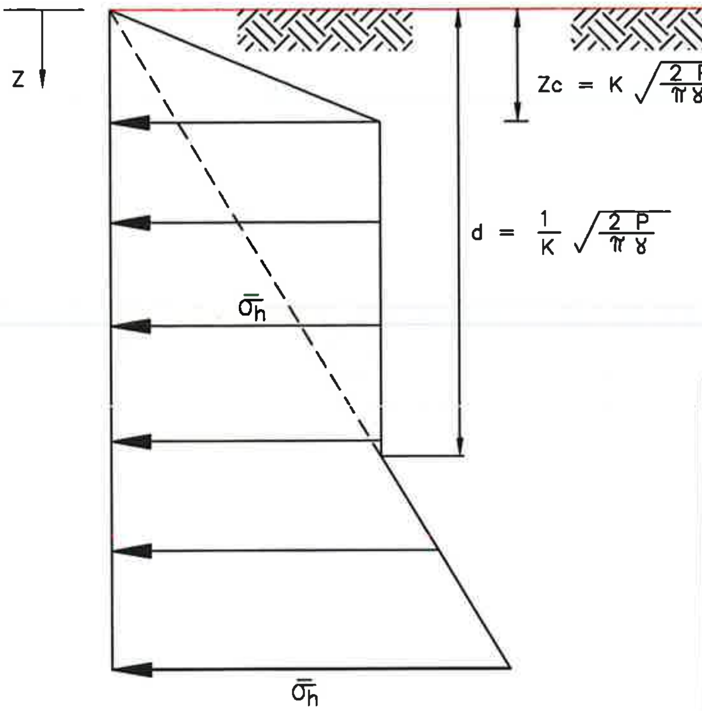
DWN BY: MD
CHK'D BY: TG
DATUM: NAD83
PROJECTION: UTM Zone 14 U
SCALE: AS SHOWN

GEOTECHNICAL INVESTIGATION
GREATER WINNIPEG WATER DISTRICT
RAILWAY BRIDGE MILE 41.3

TEST HOLE LOCATION PLAN

REV. NO.: A
DATE: FEBRUARY 2014
PROJECT NO.: WX17312
FIGURE No.: FIGURE 1

P:\JOBS\17300'S\17310'S\17312 STANTEC - GWWD BRIDGES\DRAWINGS\WX17312.DWG



EARTH PRESSURE DISTRIBUTION

FOR $Zc \leq Z \leq d$

$$\bar{\sigma}_h = \sqrt{\frac{2P\gamma}{\pi}}$$

FOR $Z > d$

$$\bar{\sigma}_h = K \cdot \gamma \cdot Z$$

TYPICAL COMPACTOR LOADS (P)			
Compactor	LOAD (P) kN/m	Compactor	LOAD (P) kN/m
Bowmag TSE	31	Bowmag BW122PD	36
Bowmag 60S	32	Bowmag 142PDB	47
Bowmag 65S	22	Bowmag 172PDB	93
Bowmag 75S	33	Dynapac LR100	42
Bowmag 90S	39	Dynapac 2100V	93
Bowmag 75AD	20	Dynapac CA121D	53
Bowmag 100AD	20	Dynapac CA121PD	54
Bowmag 120AD	34	Dynapac CA151	80
Bowmag 130AD	36	Dynapac CA151D	80
Bowmag BW122D	30	Dynapac CA151PD	96

$$P \text{ (ROLLER LOAD)} = \frac{\text{DEAD WT. OF ROLLER + CENTRIFUGAL FORCE}}{\text{WIDTH OF ROLLER}}$$

TYPICAL VALUES GIVEN IN TABLE

EARTH PRESSURE COEFFICIENTS

$K = K_o$ ("AT REST") OR K_a (ACTIVE CASE)
(SEE TEXT OF REPORT)

γ = SOIL UNIT WEIGHT
(SEE TEXT OF REPORT)

CLIENT:
STANTEC
CONSULTING LTD.

AMEC Earth & Environmental
5681-70 STREET, EDMONTON, ALBERTA T6B 3P6
PHONE 780-436-2152, FAX 780-435-8425

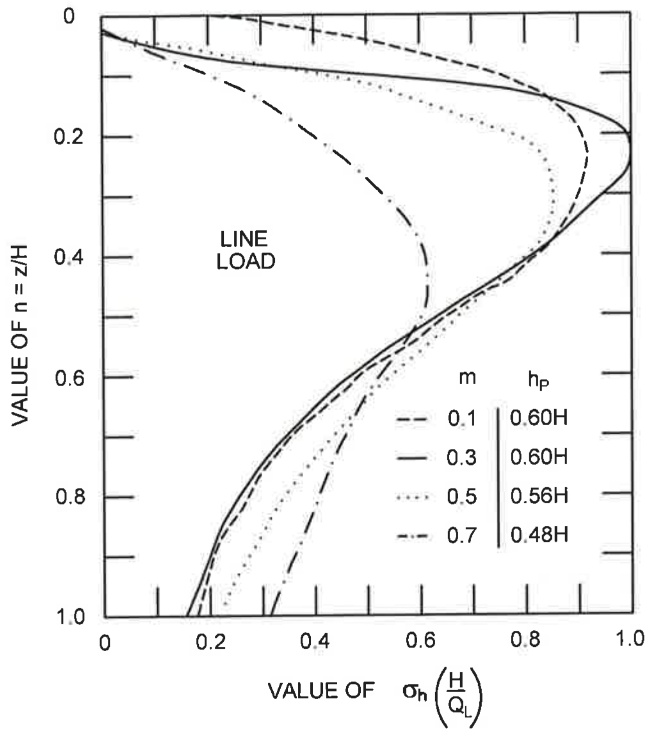
DWN BY: MD
CHK'D BY: KJ
DATUM: -
PROJECTION: -
SCALE: NOT TO SCALE

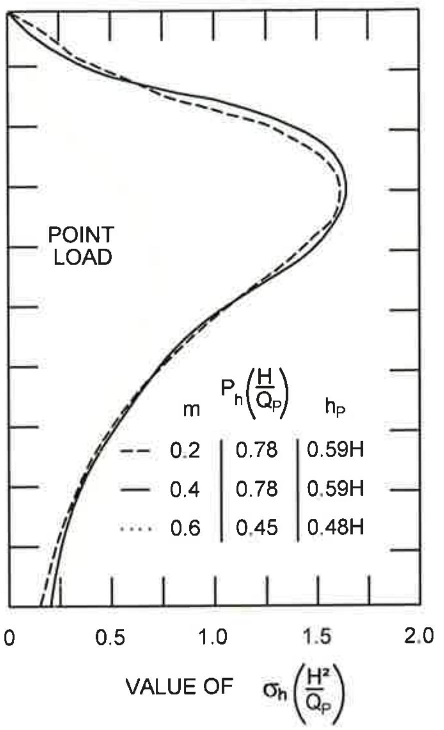
GEOTECHNICAL INVESTIGATION
GREATER WINNIPEG WATER DISTRICT
RAILWAY BRIDGE MILE 41.3

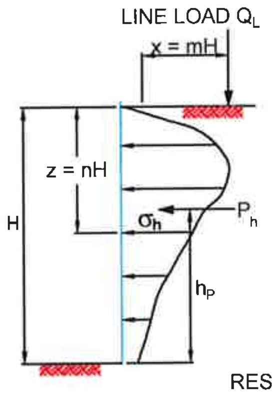
LATERAL EARTH PRESSURES
INDUCED BY COMPACTION

DATE: FEBRUARY 2014
PROJECT No.: WX17312
REV. No.: -
FIGURE No.: FIGURE 2

P:\Jobs\17300's\17310's\17312 Stantec - GWWD Bridges\Drawings\LAT PRESSURE - FIG 2.dwg - F2 (2) - Jan, 31, 2014 10 40 AM - matthews dolores







FOR m ≤ 0.4:

$$\sigma_h \left(\frac{H}{Q_L}\right) = \frac{0.20n}{(0.16 + n^2)^2}$$

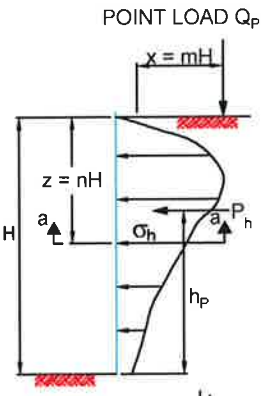
$P_h = 0.55\ Q_L$

FOR m > 0.4:

$$\sigma_h \left(\frac{H}{Q_L}\right) = \frac{1.28m^2n}{(m^2 + n^2)^2}$$

$$\text{RESULTANT } P_h = \frac{0.64\ Q_L}{(m^2 + 1)}$$

PRESSURES FROM LINE LOAD
(BOUSSINESQ EQUATION MODIFIED BY EXPERIMENT)



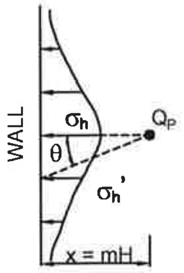
FOR m ≤ 0.4:

$$\sigma_h \left(\frac{H^2}{Q_P}\right) = \frac{0.28n^2}{(0.16 + n^2)^3}$$

FOR m > 0.4:

$$\sigma_h \left(\frac{H^2}{Q_P}\right) = \frac{1.77m^2n^2}{(m^2 + n^2)^3}$$

$$\sigma_h' = \sigma_h \ \cos^2\ (1.1\theta)$$



SECTION a-a
PRESSURES FROM POINT LOAD
(BOUSSINESQ EQUATION
MODIFIED BY EXPERIMENT)

CLIENT:
STANTEC
CONSULTING LTD.

AMEC Earth & Environmental
5681-70 STREET, EDMONTON, ALBERTA, T6B 3P6
PHONE 780-436-2152 FAX 780-435-8425

DWN BY: MD
CHK'D BY: KJ
DATUM: -
PROJECTION: -
SCALE: NOT TO SCALE

GEOTECHNICAL INVESTIGATION
GREATER WINNIPEG WATER DISTRICT
RAILWAY BRIDGE MILE 41.3

LATERAL PRESSURES DUE TO
SURCHARGE POINT AND LINE LOADS

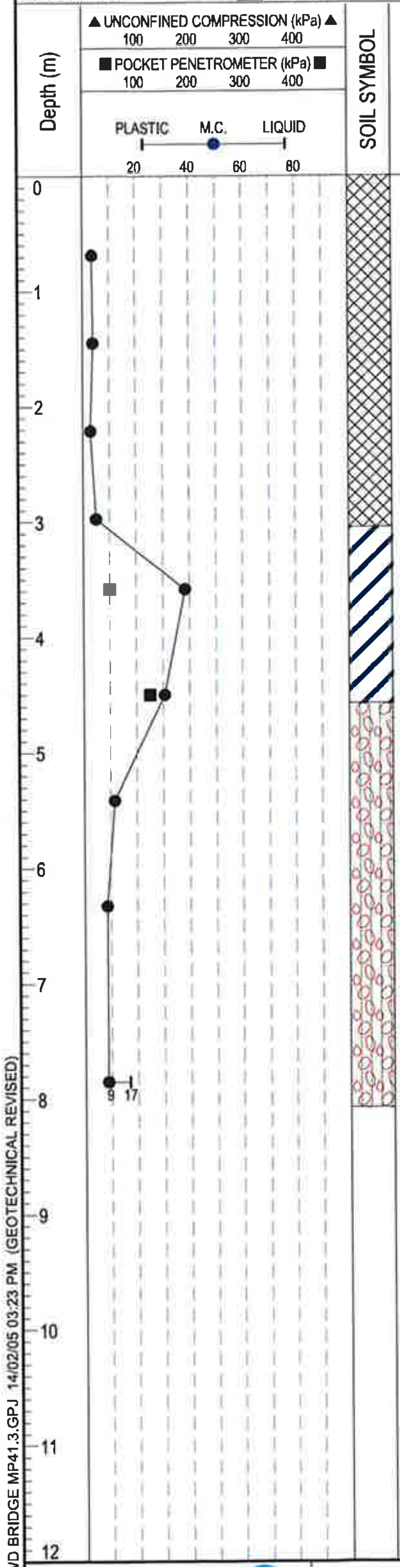
DATE: FEBRUARY 2014
PROJECT No.: WX17312
REV. No.: -
FIGURE No.: FIGURE 3

P:\Jobs\17300's\17310's\17312 Stantec - GWWD Bridges\Drawings\LAT PRESSURE - FIG 3 dwg - F3 (2) - Jan. 31, 2014 10:40 AM - matthews dolores

APPENDIX A

PROJECT: GWWD Bridge Mile 41.3	DRILLED BY: Maple Leaf Drilling Ltd.	BORE HOLE NO: **TH01**
CLIENT: Stantec Consulting Ltd.	DRILL TYPE: Acker MP5 Track Rig	PROJECT NO: WX17312
LOCATION: RM of Springfield, Manitoba	DRILL METHOD: 125 mm SSA	ELEVATION: 99.7 m

SAMPLE TYPE	■ Shelby Tube	◺ No Recovery	☒ SPT (N)	☰ Grab Sample	▥ Split-Pen	▮ Core
BACKFILL TYPE	■ Bentonite	☐ Pea Gravel	▨ Drill Cuttings	⁘ Grout	▥ Slough	⁘ Sand



MUSCS	SOIL DESCRIPTION	ELEVATION (m)
SP	SAND (FILL) - and gravel, poorly graded, medium to coarse grained, dense (inferred), frozen, brown	99.7
CH	CLAY - silty, high plastic, moist, firm, dark grey, trace rootlets, trace organics - stiff, occasional black organic streaking below 3.6 m	
CL-ML	SILT (TILL) - some sand, some gravel, low to non plastic, moist to damp, very dense, grey	

SAMPLE TYPE	SAMPLE NO	SPT (N)
☰	1	
☰	2	
☰	3	
☰	4	
☰	5	
☰	6	
■	7	
☒	8	71
☒	9	50/140
☒	10	82

COMMENTS

TH Coordinates (UTM):
5516021.5mN
690232.9mE

- Drill method switched to 175 mm HSA below 4.6 m to control sloughing of overlying sand

ELEVATION (m): 99, 98, 97, 96, 95, 94, 93, 92, 91, 90, 89, 88

PRACTICAL SPT REFUSAL AT 8.1 m BELOW GRADE IN VERY DENSE TILL

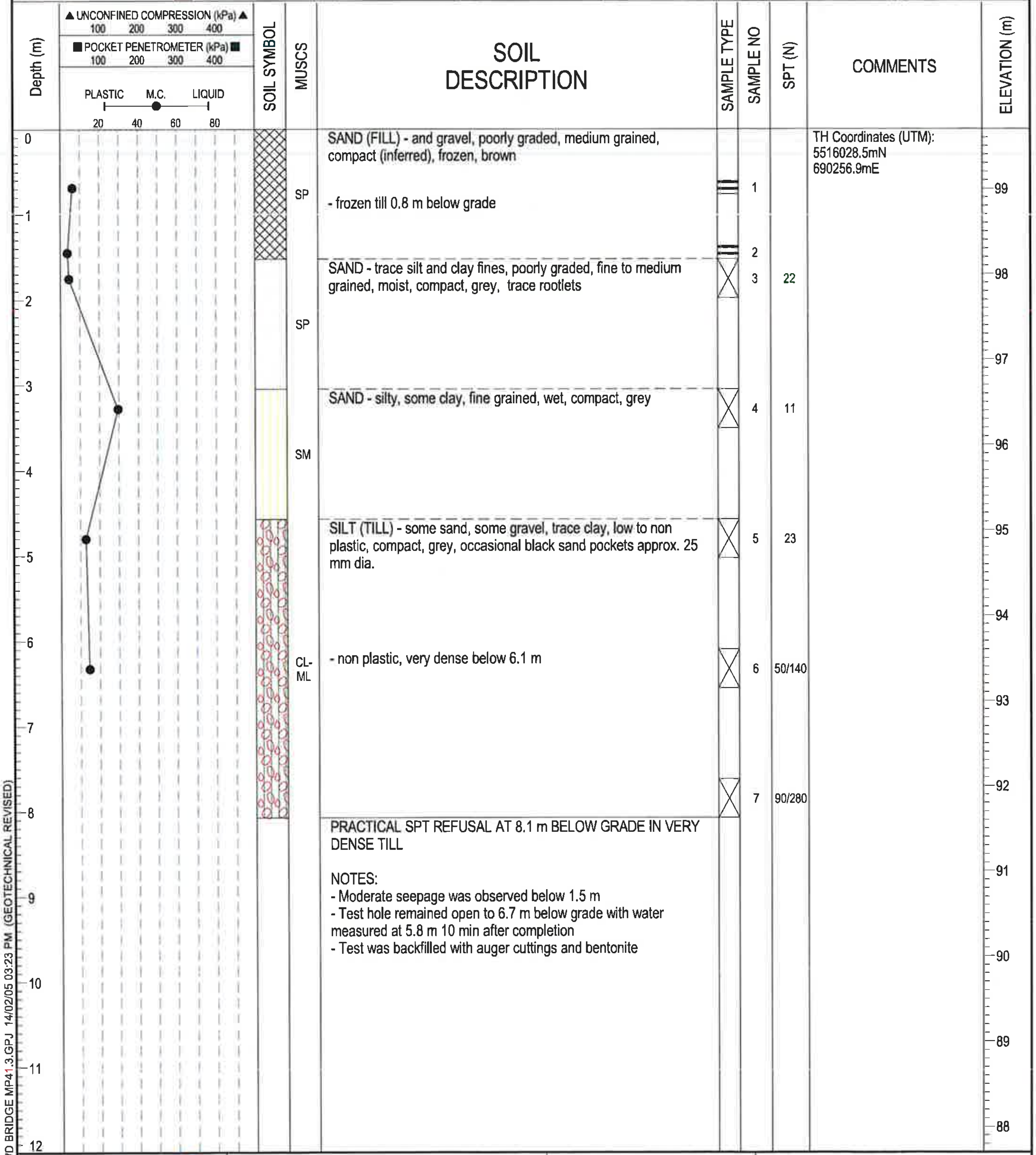
NOTES:
- Significant sloughing was observed from 0 to 3.0 m below grade.
- Slight seepage was observed between 0 to 3.7 m and 4.6 m to 8.1 m below grade.
- Test hole remained open to 6.4 m below grade with water measured at 5.8 m 10 min after completion.
- Test hole was backfilled with auger cuttings and bentonite.

17312 GWWD BRIDGE MP41.3.GPJ 14/02/05 03:23 PM (GEOTECHNICAL REVISED)

amec / **AMEC Environment & Infrastructure Winnipeg, Manitoba**	LOGGED BY: HWP	COMPLETION DEPTH: 8.1 m
	REVIEWED BY: KJ	COMPLETION DATE: 17 December 2013
	Figure No. A1	Page 1 of 1

PROJECT: GWWD Bridge Mile 41.3	DRILLED BY: Maple Leaf Drilling Ltd.	BORE HOLE NO: **TH02**
CLIENT: Stantec Consulting Ltd.	DRILL TYPE: Acker MP5 Track Rig	PROJECT NO: WX17312
LOCATION: RM of Springfield, Manitoba	DRILL METHOD: 175 mm HSA	ELEVATION: 99.7 m

SAMPLE TYPE	■ Shelby Tube	◸ No Recovery	☒ SPT (N)	☰ Grab Sample	▥ Split-Pen	◧ Core
BACKFILL TYPE	■ Bentonite	☐ Pea Gravel	▨ Drill Cuttings	⁘ Grout	▥ Slough	⁘ Sand



MUSCS	SOIL DESCRIPTION	SAMPLE TYPE	SAMPLE NO	SPT (N)	COMMENTS
SP	SAND (FILL) - and gravel, poorly graded, medium grained, compact (inferred), frozen, brown - frozen till 0.8 m below grade	☰ ☰	1 2		TH Coordinates (UTM): 5516028.5mN 690256.9mE
SP	SAND - trace silt and clay fines, poorly graded, fine to medium grained, moist, compact, grey, trace rootlets	☒	3	22	
SM	SAND - silty, some clay, fine grained, wet, compact, grey	☒	4	11	
CL-ML	SILT (TILL) - some sand, some gravel, trace clay, low to non plastic, compact, grey, occasional black sand pockets approx. 25 mm dia. - non plastic, very dense below 6.1 m	☒ ☒ ☒	5 6 7	23 50/140 90/280	

PRACTICAL SPT REFUSAL AT 8.1 m BELOW GRADE IN VERY DENSE TILL

NOTES:
- Moderate seepage was observed below 1.5 m
- Test hole remained open to 6.7 m below grade with water measured at 5.8 m 10 min after completion
- Test was backfilled with auger cuttings and bentonite

AMEC Environment & Infrastructure **Winnipeg, Manitoba**	LOGGED BY: HWP	COMPLETION DEPTH: 7.6 m
	REVIEWED BY: KJ	COMPLETION DATE: 17 December 2013
	Figure No. A2	Page 1 of 1

EXPLANATION OF TERMS AND SYMBOLS

The terms and symbols used on the borehole logs to summarize the results of field investigation and subsequent laboratory testing are described in these pages.

It should be noted that materials, boundaries and conditions have been established only at the borehole locations at the time of investigation and are not necessarily representative of subsurface conditions elsewhere across the site.

TEST DATA

Data obtained during the field investigation and from laboratory testing are shown at the appropriate depth interval.

Abbreviations, graphic symbols, and relevant test method designations are as follows:

*C	Consolidation test	*ST	Swelling test
D_R	Relative density	TV	Torvane shear strength
*k	Permeability coefficient	VS	Vane shear strength
*MA	Mechanical grain size analysis	w	Natural Moisture Content (ASTM D2216)
	and hydrometer test	w_l	Liquid limit (ASTM D 423)
N	Standard Penetration Test (CSA A119.1-60)	w_p	Plastic Limit (ASTM D 424)
N_d	Dynamic cone penetration test	E_f	Unit strain at failure
NP	Non plastic soil	γ	Unit weight of soil or rock
pp	Pocket penetrometer strength	γ_d	Dry unit weight of soil or rock
*q	Triaxial compression test	ρ	Density of soil or rock
q_u	Unconfined compressive strength	ρ_d	Dry Density of soil or rock
*SB	Shearbox test	C_u	Undrained shear strength
SO_4	Concentration of water-soluble sulphate	→	Seepage
		▼	Observed water level

* The results of these tests are usually reported separately

Soils are classified and described according to their engineering properties and behaviour.

The soil of each stratum is described using the Unified Soil Classification System[1] modified slightly so that an inorganic clay of "medium plasticity" is recognized.

The modifying adjectives used to define the actual or estimated percentage range by weight of minor components are consistent with the Canadian Foundation Engineering Manual[2].

Relative Density and Consistency:

Cohesionless Soils

Relative Density	SPT (N) Value
Very Loose	0-4
Loose	4-10
Compact	10-30
Dense	30-50
Very Dense	>50

Cohesive Soils

Consistency	Undrained Shear Strength c_u (kPa)	Approximate SPT (N) Value
Very Soft	0-12	0-2
Soft	12-25	2-4
Firm	25-50	4-8
Stiff	50-100	8-15
Very Stiff	100-200	15-30
Hard	>200	>30

Standard Penetration Resistance ("N" value)

The number of blows by a 63.6kg hammer dropped 760 mm to drive a 50 mm diameter open sampler attached to "A" drill rods for a distance of 300 mm after an initial penetration of 150 mm.

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[1] "Unified Soil Classification System", Technical Memorandum 36-357 prepared by Waterways Experiment Station, Vicksburg, Mississippi, Corps of Engineers, U.S. Army. Vol. 1 March 1953.

[2] "Canadian Foundation Engineering Manual", 3rd Edition, Canadian Geotechnical Society, 1992.

MODIFIED UNIFIED CLASSIFICATION SYSTEM FOR SOILS

MAJOR DIVISIONS			SYMBOLS			TYPICAL DESCRIPTION	LABORATORY CLASSIFICATION CRITERIA
			USCS	GRAPH	COLOUR		
COARSE GRAINED SOILS (MORE THAN HALF BY WEIGHT LARGER THAN 75um)	GRAVELS MORE THAN HALF THE COARSE FRACTION LARGER THAN 4.75mm	CLEAN GRAVELS (TRACE OR NO FINES)	GW	▨	RED	WELL GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	$C_u=D_{60}/D_{10} >4$; $C_c=(D_{30})^2/(D_{10}xD_{60}) = 1$ to 3
			GP	▨	RED	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	NOT MEETING ABOVE REQUIREMENTS
		DIRTY GRAVELS (WITH SOME OR MORE FINES)	GM	▨	YELLOW	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES	ATTERBERG LIMITS BELOW "A" LINE OR PI LESS THAN 4
			GC	▨	YELLOW	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES	ATTERBERG LIMITS ABOVE "A" LINE AND PI MORE THAN 7
	SANDS MORE THAN HALF THE COARSE FRACTION SMALLER THAN 4.75mm	CLEAN SANDS (TRACE OR NO FINES)	SW	▨	RED	WELL GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	$C_u=D_{60}/D_{10} >6$; $C_c=(D_{30})^2/(D_{10}xD_{60}) = 1$ to 3
			SP		RED	POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	NOT MEETING ABOVE REQUIREMENTS
		DIRTY SANDS (WITH SOME OR MORE FINES)	SM	▨	YELLOW	SILTY SANDS, SAND-SILT MIXTURES	ATTERBERG LIMITS BELOW "A" LINE OR PI LESS THAN 4
			SC	▨	YELLOW	CLAYEY SANDS, SAND-CLAY MIXTURES	ATTERBERG LIMITS ABOVE "A" LINE AND PI MORE THAN 7
FINE-GRAINED SOILS (MORE THAN HALF BY WEIGHT SMALLER THAN 75um)	SILTS BELOW "A" LINE NEGLIGIBLE ORGANIC CONTENT	$W_L < 50\%$	ML	▥	GREEN	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY SANDS OF SLIGHT PLASTICITY	CLASSIFICATION IS BASED UPON PLASTICITY CHART (SEE BELOW)
		$W_L > 50\%$	MH	▥	BLUE	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS, FINE SAND OR SILTY SOILS	
	CLAYS ABOVE "A" LINE NEGLIGIBLE ORGANIC CONTENT	$W_L < 30\%$	CL	▨	GREEN	INORGANIC CLAYS OF LOW PLASTICITY, GRAVELLY, SANDY OR SILTY CLAYS, LEAN CLAYS	
		$30\% < W_L < 50\%$	CI	▨	GREEN-BLUE	INORGANIC CLAYS OF MEDIUM PLASTICITY, SILTY CLAYS	
		$W_L > 50\%$	CH	▨	BLUE	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS	
	ORGANIC SILTS & CLAYS BELOW "A" LINE	$W_L < 50\%$	OL	▥	GREEN	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY	WHENEVER THE NATURE OF THE FINES CONTENT HAS NOT BEEN DETERMINED, IT IS DESIGNATED BY THE LETTER "F", E.G. SF IS A MIXTURE OF SAND WITH SILT OR CLAY
		$W_L > 50\%$	OH	▨	BLUE	ORGANIC CLAYS OF HIGH PLASTICITY	
HIGHLY ORGANIC SOILS			PT	▨	ORANGE	PEAT AND OTHER HIGHLY ORGANIC SOILS	STRONG COLOUR OR ODOUR, AND OFTEN FIBROUS TEXTURE

SPECIAL SYMBOLS

LIMESTONE	▦	OILSAND	○
SANDSTONE		SHALE	▤
SILTSTONE	⁘	FILL (UNDIFFERENTIATED)	▩

SOIL COMPONENTS

FRACTION	U.S. STANDARD METRIC SIEVE SIZE	
GRAVEL	PASSING	RETAINED
COARSE	76mm	19mm
FINE	19mm	4.75mm
SAND		
COARSE	4.75mm	2.00mm
MEDIUM	2.00mm	425μm
FINE	425μm	75μm
FINES (SILT OR CLAY BASED ON PLASTICITY)	75μm	

DEFINING RANGES OF PERCENT BY WEIGHT OF MINOR COMPONENTS	
PERCENT	DESCRIPTOR
35 - 50	AND
30 - 35	Y / EY
10 - 20	SOME
1 - 10	TRACE

OVERSIZED MATERIAL

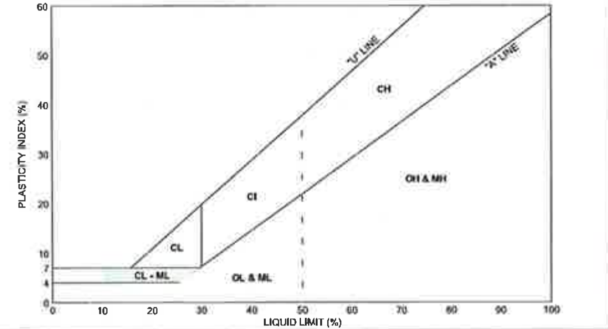
ROUNDED OR SUBROUNDED:

COBBLES 76mm to 200mm
BOULDERS > 200mm

NOT ROUNDED:

ROCK FRAGMENTS ? 76mm
ROCKS > 0.76 CUBIC METRE IN VOLUME

PLASTICITY CHART FOR SOILS PASSING 425μm SIEVE



NOTES:

1. ALL SIEVE SIZES MENTIONED ARE U.S. STANDARD ASTM E.11.
2. COARSE GRAINED SOILS WITH TRACE TO SOME FINES GIVEN COMBINED GROUP SYMBOLS, E.G. GW-GC IS A WELL GRADED GRAVEL SAND MIXTURE WITH TRACE TO SOME CLAY.
3. DUAL SYMBOLS ARE USED TO INDICATE BORDERLINE SOIL CLASSIFICATIONS.

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