Geotechnical Design Report

Radium Wildlife Crossings – North Crossing

Prepared for:

Ministry of Transportation and Infrastructure

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Signature Page

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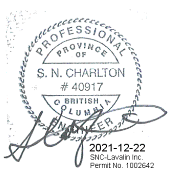

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1 Introduction and Project Scope

SNC-Lavalin Inc. (SNC-Lavalin) completed a geotechnical investigation in support of proposed wildlife crossing construction along Highway 93/95 south of Radium Hot Springs, BC (hereinafter referred to as the 'Site'). For purposes of the investigation, drilling locations at the Site were categorized under the preferred crossing locations as the 'North Crossing' and 'South Crossing' as shown on Drawing 680927-001. The objective of the drilling investigation was to determine subsurface and groundwater conditions at the North and South Crossings which are located approximately 1.1 km and 2.3 km south of the intersection of Stanley Street and Highway 93/95, respectively.

The purpose of this report is to provide preliminary geotechnical design recommendations for the proposed development at the North Crossing location. The BC Ministry of Transportation and Infrastructure (MOTI) has identified an overpass structure to be the preferred crossing type at the North Crossing. Potential crossing alternatives identified by MOTI include pre-cast concrete and steel plate arch structures with near-vertical mechanically stabilised earth (MSE) wall end treatments, or a bridge structure with concrete abutments. This report provides conceptual design recommendations that may be implemented for any of the potential options noted above.

Based on preliminary information provided by COWI North America Ltd. (COWI), the pre-cast concrete arch unfactored vertical loading is anticipated to be 490 kN/m and the unfactored lateral loading (into the backfill) would be about 13 kN/m. No anticipated loading information was provided for the steel plate arch or bridge structure at the time of this report.

The geotechnical comments and recommendations discussed herein are based on SNC-Lavalin's geotechnical investigation factual data report[1] for the Site; soil deposits referenced in this report are based on those presented in the factual data report. The scope of this design report is limited to the geotechnical aspects of the proposed North Crossing structure, and therefore, does not include any commentary for the South Crossing location. Furthermore, no information pertaining to detailed design of any part of the North or South Crossings is provided in this report.

[1] SNC-Lavalin Inc. 2021. *Geotechnical Investigation, Radium Wildlife Crossings – Factual Data Report*. September 3, 2021. Nelson, BC

2 Geotechnical Discussion and Recommendations

Based on the subsurface information collected at the Site during SNC-Lavalin's June 2021 investigation, the proposed development is considered feasible from a geotechnical perspective. Dependent on bearing resistance requirements, foundations for the proposed crossing may be founded in deposits and at depths below ground surface as described in the recommendations provided in the following subsections. It should be noted that the existing surficial organic soils and pavement structure soils should be removed from within the proposed construction footprint, as described below. In general, construction should adhere to the MOTI 2020 Standard Specifications (SS 2020)[2] with additional guidance from the following subsections.

2.1 General

This section contains comments and geotechnical recommendations that apply to the full scope of construction at the North Crossing location.

2.1.1 Frost Protection

The Government of Canada website[3] was used to assess climate history near the Site. Normals data from the Kootenay NP West Gate weather station, which is located approximately 2.3 km north of the Site, and the Wasa weather station, located approximately 94.4 km south of the Site, were evaluated. Climate data for maximum and minimum temperatures are similar at these stations as they are located within the same river valley along Highway 93/95 and are at similar elevations. A freezing index of 655 degree-days Celsius was selected for the Site based on data from the Wasa station as similar data was not available at the Kootenay NP West Gate station.

Based on the selected freezing index for the Site, it is recommended that foundations be provided with a minimum of 1.5 m of soil cover for frost protection purposes. If sufficient soil cover cannot be provided due to design constraints, then an alternative method of insulation (such as rigid polystyrene insulation) may be required to protect the foundations from frost heave.

2.1.2 Soil Stripping

It is recommended that at a minimum all vegetation, surficial organic soils, and pavement structure soils be completely removed from the proposed development footprint (ditches, through-cut slopes, foundations, etc.). Depending on loading requirements and selected foundation type, the silty granular, sand and gravel, and silt and clay deposits may need to be stripped to expose the underlying compact to dense till soils. Table 1 below provides an approximate guide for stripping depths for shallow foundations, depending on foundation bearing strata.

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[2] BC Ministry of Transportation and Infrastructure (MOTI), (2020). *2020 Standard Specifications for Highway Construction, Volume 1 and 2.* November 20, 2020.

[3] Government of Canada (2021). *Canadian Climate Normals.* Retrieved July 19, 2021 from https://climate.weather.gc.ca/climate_normals/

Table 1: Approximate Soil Stripping Depth for Shallow Foundations

Foundation Bearing Strata	Estimated Stripping Depth (mbgs)	Stripped Materials
Silty Granular, Sand and Gravel, or Silt and Clay Deposits	0.2 – 1.5	Surficial Organics and Pavement Structure Soils
Till Deposits	0.6 – 7.0	Surficial Organics, Pavement Structure Soils, Silty Granular, Sand and Gravel, and Silt and Clay Deposits

Grubbing of organics is expected to be minimal as vegetation consists primarily of medium to long length grass at the proposed development location; ditch bottoms may have thicker fill and debris deposits. The soil stripping should continue to the extent of the foundation footprint, cut slope requirements, permanent cut and fill slope requirements (Section 2.1.3), and/or structural grade fill requirements (Section 2.1.4).

2.1.3 Permanent Cut and Fill Slopes

Based on the proposed development plan, permanent cut slopes are not expected at the Site. Should permanent cut slopes be required, they may be developed in the silty granular, sand and gravel, and till deposits with side slopes no steeper than 2 Horizontal to 1 Vertical (2H:1V); final slope designs should be reviewed by a geotechnical engineer.

Permanent fill slopes (earth berms) constructed along the edges of the chosen overpass structure to block line of sight of wildlife and provide a barrier to the edge of the overpass may be constructed with general grade fill (Section 2.1.5). Prior to placement, earth berm soils should be approved by a geotechnical engineer. Unreinforced fill slopes should be developed with side slopes no steeper than 2H:1V.

All cut and fill slopes should be smoothed and re-vegetated with grasses and/or native vegetation to prevent erosion; a 100 mm thick layer of topsoil should be placed at surface to provide a growing medium for vegetation. Slope crests must also be rounded to shed surface runoff.

2.1.4 Structural Grade Fill

Backfill below the proposed crossing structure foundation or fill that may be expected to support other infrastructure (e.g., MSE walls) should be considered structural grade fill. Structural grade fill should consist of well-graded 75 mm minus sand and gravel containing less than 5% passing the 0.075 mm (No. 200) sieve size, similar to MOTI Bridge End Fill material. Structural grade fill should be placed in horizontal lifts not exceeding 300 mm in loose thickness and must be compacted to at least 100% standard Proctor maximum dry density (SPMDD [ASTM D 698]) within 2% of its optimum moisture content for compaction.

Structural grade fill placed on slopes should be keyed into the slope using a series of steps to minimize the risk of a potential weak zone or slip plane between the structural grade fill and native soils. No organic soils or frozen material should be placed as structural grade fill.

Structural grade fill placed below a structure should extend a lateral distance equivalent to the thickness of the structural grade fill plus one metre, and the structural grade fill should form a slope no steeper than 1H:1V to the base of the excavation.

2.1.5 General Grade Fill

General grade fill may be used within the central portion of an arch crossing structure that is at least 1.5 m back from an outside surface (e.g., culvert inside surface, MSE wall, etc.).

General grade fill should comprise MOTI Type D (Suitable sub-class) material containing less than 20% passing the 0.075 mm (No. 200) sieve size. Type D material should be free of organics and other deleterious materials, high plastic clays, silts, and should contain no more than 15% by volume rock larger than 150 mm nominal diameter. Type D soils must be placed in horizontal lifts as per Table 201-A of the SS 2020.

Subject to the review of a geotechnical engineer, it is anticipated that the silty granular and sand and gravel deposits, if free of organics and deleterious materials, may be considered suitable for re-use as general grade fill. The silty granular deposits may require moisture conditioning and/or sorting to break up cohesive clumps prior to placement.

2.1.6 Subgrade Preparation

Following the completion of soil stripping as per Section 2.1.2, the subgrade should be leveled and compacted to a minimum of 100% SPMDD. Boulders and cobbles, if visible and protruding from the subgrade surface, should be removed and replaced with structural grade fill (Section 2.1.4).

The native silty sand, sand and gravel, and till deposits are considered suitable for the subgrade of the proposed crossing structure, depending on loading requirements. Any areas where soft or yielding soils are encountered should be sub-excavated and replaced using structural grade fill in accordance with Section 2.1.4. Structural and general grade fill (Sections 2.1.4, and 2.1.5, respectively) must not be placed on subgrade soils that are frozen, have ponded water, or are excessively wet or soft.

Where subgrade preparation extends into the till deposits and perched groundwater is encountered or is likely to be encountered, subgrade should be sloped to allow infiltrated water to drain from the subgrade surface or a perimeter drain (Section 2.1.9) should be installed to allow drainage to a stormwater management system,

2.1.7 Base Layer

A base layer should be placed directly below the proposed crossing foundation and MSE wall segments to provide a consistent work surface that will evenly distribute the loading from foundations. The base layer may be founded on subgrade soils as defined in Section 2.1.6 to provide a free-draining layer directly below the foundation. The base layer should be a minimum of 300 mm in compacted thickness and should consist of MOTI 25 mm Well-Graded Base material. The base layer must be compacted to a minimum of 100% SPMDD within 2% of its optimum moisture content during compaction.

The base layer, if placed and compacted within the till deposits and expected to encounter the perched groundwater table should be provided drainage (Section 2.1.9). A Base layer placed and compacted within the granular native soils is expected to drain freely through the underlying subgrade soils and additional site drainage is not required.

2.1.8 Dewatering

Localized, perched groundwater was encountered in BH21-02 at a depth of 4.6 mbgs at the time of SNC-Lavalin's June 2021 geotechnical field investigation. Based on moisture contents and conditions encountered at the Site during the field investigation, dewatering is not expected to be required for most construction activities at the Site. Should groundwater be encountered or following precipitation events, it is expected that excavations could be kept dry through conventional sump and pump methods.

Ponded water may cause subgrade soils to soften and sub-excavation and replacement with structural grade fill (Section 2.1.4) may be required. Excavations should be protected from surface runoff during construction to reduce the volume of ponding on the excavation base and prevent erosion on excavation slopes.

2.1.9 Site Drainage

The Site should be graded such that surface runoff is directed away from the North Crossing structure and MSE walls to an engineered ditch system or natural drainage system on the downslope side of all infrastructure. Perimeter drains consistent with SS 2020 Section 318 should be installed at the base of MSE walls, and to allow drainage from foundations where excavation has extended into the till deposits and perched groundwater is likely to be encountered. Perimeter drains should drain to a daylighted drainage outlet downslope or a stormwater management system. Erosion protection specified by others should be provided for all daylighted drainage outlets.

2.2 Conventional Strip Footings

The proposed crossing structure can be supported on conventional strip footings founded on a base layer (Section 2.1.7) overlying the native silty sand, sand and gravel, or till deposits depending on final loading requirements at the North Crossing location.

A limit states design methodology has been utilized to determine the bearing resistance at the Site. Footings founded below the frost penetration depth (1.5 m from Section 2.1.1) on the base layer (Section 2.1.7) can be designed using Serviceability Limit State (SLS) and factored Ultimate Limit State (ULS) soil bearing resistances as per Table 2 below. A minimum of 1.5 m embedment is required for all footings. Based on Section 6.9 of the Canadian Highway Bridge Design Code (CHBDC S6-14), for major-route bridges under a typical degree of understanding of the ground properties, a geotechnical foundation factor of 0.5 for bearing resistance has been selected based on the investigation methodology and foundation type. Embedment depth is based on depth the bearing strata is encountered below existing ground surface. The bearing resistances provided in Table 2 may only be applied if the foundation bearing strata is encountered at or below the specified embedment depth. The depth to the till deposits varied across the proposed crossing footprint, and although till deposits may be encountered at less than 1.5 m as observed in the test pits adjacent to the highway, there are locations within the proposed development footprint where till deposits are as much as 7 m below the road grade.

Table 2: SLS and Factored ULS Soil Bearing Resistances

Foundation Bearing Strata	Embedment Depth (m)	Strip Footing Width (m)	SLS Bearing Resistance (kPa)	Factored ULS Bearing Resistance (kPa)	Equivalent SLS Vertical Load (kN/m)
Silty Granular, Sand and Gravel, or Silt and Clay Deposits	1.5	3.0	150	350	340
Till Deposits	1.5	1.0	460	690	420
Till Deposits	5.0	1.0	600	900	780

Provided that the foundation materials are not loosened or disturbed, it is anticipated that foundations designed for the above stated bearing resistances will be subject to settlements, both total and differential, of less than 25 mm. As such, care shall be taken during excavation to avoid disturbance of the footing bearing surface. If the bearing soils are loosened or disturbed, the soil should be over-excavated at least 300 mm and replaced with structural grade fill (Section 2.1.4).

The above bearing resistances are based on assumed footing widths and embedment depths. Should the final design of the footings differ from the assumed measurements, SNC-Lavalin should be given the opportunity to review, and adjust if necessary, the results of this analysis. Foundation subgrade soils should be reviewed by a geotechnical engineering to confirm bearing strata.

2.3 Pile Foundations

The proposed crossing structure can also be supported on pile foundations at the North Crossing location. Driven steel pipe piles were identified by MOTI as the preferred pile foundation type. The analysis outlined in the following subsections is based on installation of 610 mm diameter open-ended driven steel pipe piles with 19.1 mm wall thickness. Should the final foundation design differ from these measurements, SNC-Lavalin should be given the opportunity to review, and adjust if necessary, the results of this analysis.

It should be noted that granular soils encountered at the Site may impact driving of the piles. Should a thinner wall thickness be desired, pile driving shoes may be required to protect piles during installation. Further feasibility assessment of pile wall thickness could be completed when pile driving hammer size is known.

Pile foundations may be the preferred foundation type dependent on constructability concerns such as required excavation footprint, temporary shoring and other associated costs.

2.3.1 Pile Axial Resistance

The unfactored ultimate axial geotechnical pile resistance for the proposed open-ended steel pipe piles was estimated using the Beta Method (Chandler 1968, Burland 1973, Meyerhof 1976, and Fleming et al. 1992) as predominantly granular soil deposits were encountered at the Site. Soil parameters used for this analysis are based on data collected during SNC-Lavalin's June 2021 field investigation and the Canadian Foundation Engineering Manual (CFEM) and American Petroleum Institute (API) recommended practice guidelines. Soil parameters selected for axial pile resistance calculations are provided below in Table 3. Based on soil type (generally cohesionless to till deposits), pile diameter (greater than 500 mm), and maximum pile length (less than 12 m), soil plugging was not considered in the single pile axial resistance calculation.

Table 3: Soil Parameters Selected for Single Pile Axial Resistance Calculation

Layer Description	Depth (mbgs)		Unit Weight (kN/m^3)	β	N_t	q_s limit* (kPa)	q_t limit* (kPa)
	From	To					
Sand with Gravel (compact)	0.0	1.5	18.5	0.6	50	81.3	4,800
Silty Sand with Gravel (loose to compact)	1.5	4.0	18.0	0.3	40	67.0	2,900
Gravel with Sand (compact)	4.0	6.0	18.5	0.8	100	81.3	4,800
Gravel with Silt and Sand (compact)	6.0	7.0	18.5	0.7	100	81.3	4,800
Silty Gravel with Sand [Till] (very dense)	7.0	10.0	18.5	1.0	150	105.25	10,800

*maximum unit shaft resistance is based on API (RP 2A-WSD)

During SNC-Lavalin's June 2021 field investigation, a localized, perched groundwater table (GWT) was encountered in BH21-02 (near the northwest corner of the proposed North Crossing) at 4.6 mbgs. As groundwater was only encountered at this location, separate analyses were performed considering a GWT at 4.5 mbgs and 15 mbgs. Plots of unfactored single pile axial resistance versus depth for both conditions examined are attached in Appendix I and include separate curves for shaft, toe, and total resistance. Plots considering the GWT at either 4.5 mbgs or 15 mbgs can be used to obtain unfactored single pile axial resistance at the North Crossing. However, the case considering groundwater at 4.5 mbgs may provide a more conservative value should groundwater be encountered at the Site during the lifetime of the structure.

Based on the pile resistance calculations, it is expected that piles will be driven into compact to dense silty gravel with sand below 7 m depth, as such it is expected that the total static post-construction settlement of the piles will be less than 25 mm.

2.3.1.1 Geotechnical Resistance Factor

The provided unfactored pile axial resistance must be multiplied by a geotechnical resistance factor to provide factored axial geotechnical resistance for a single pile. Based on CHBDC S6-14, Section 6.9 and Section 4.4.6.2, for major-route bridges under a typical degree of understanding of the ground properties, the geotechnical resistance factors presented in Table 4 may be applied for compressive and tensile (uplift) loading conditions. Separate resistance factors are provided dependent on the implementation of Pile Driving Analysis (PDA) testing during construction. The resistance factors provided in Table 4 have been determined in accordance with Section 4.6.3.1 of the MOTI Supplement to CHBDC S6-14.

Table 4: Geotechnical Resistance Factors

Condition	Resistance Factor for Compression (Without PDA Test)	Resistance Factor for Compression (With PDA Test)	Resistance Factor for Tension (With and Without PDA Test)
Static – ULS	0.4	0.5	0.3
475-Year Earthquake**	0.5	0.6	0.4
2,475-Year Earthquake**	0.7	0.7	0.6

**Note: as per Table 4.15 CSA S6-14, assumed "Immediate Service" or "Minimal Damage" after a 475-year earthquake event, and "Service Disruption" or "Extensive Damage" after a 2,475-year earthquake event.

2.3.2 Pile Lateral Response Analysis (P-Y Curves)

Lateral analysis of the proposed open-ended steel pipe piles was completed using the computer program, LPILE (Ensoft 2019). The program computes deflection, shear force and bending moment, and soil response with respect to depth in non-linear soils. P-Y curves were generated for the proposed pile dimensions under static conditions for pile depths ranging between 1.0 m and 10.0 m. Separate analyses were conducted considering a GWT at 4.5 mbgs and 15 mbgs to reflect groundwater conditions encountered during SNC-Lavalin's June 2021 field investigation. Input soil parameters and models selected for the LPILE analyses are provided in Table 5 below. Tabular results and P-Y curves from the LPILE analyses are provided in Appendix II and are available in Excel format, if needed. Curves considering the GWT at either 4.5 mbgs or 15 mbgs can be used to assess lateral pile response at the North Crossing. However, the case considering groundwater at 4.5 mbgs may provide a more conservative value should groundwater be encountered at the Site during the lifetime of the structure.

Table 5: Soil Parameters Selected for LPILE Analysis

Layer Description	Depth (mbgs)		Effective Unit Weight (kN/m^3)		Soil Model	Subgrade Constant (k)* (kN/m^2)	Φ' (°)
	From	To	GWT at 4.5 m	GWT at 15 m			
Sand with Gravel (compact)	0	1.5	18.5	18.5	Reese Sand	22,000	32
Silty Sand with Gravel (loose to compact)	1.5	4	18.0	18.0	Reese Sand	6,500	30
Gravel with Sand (compact)	4	6	8.5	18.5	Reese Sand	30,000	34
Gravel with Silt and Sand (compact)	6	7	8.5	18.5	Reese Sand	28,000	33
Silty Gravel with Sand [Till] (very dense)	7	10	8.5	18.5	Reese Sand	600,000	36

* K – The Subgrade Constant represents the relationship between the elasticity modulus (Es) of the soil and the depth of the layer.

Piles should be driven below the point of fixity, or until axial capacity is achieved based on project loading requirements, whichever is greater.

2.4 Retaining Walls

Near-vertical MSE walls are expected to be constructed at the Site to contain backfill placed between the proposed crossing structure and existing through-cut slopes. This section contains comments and geotechnical recommendations that apply to the construction of MSE walls at the North Crossing location.

2.4.1 Backfill

Backfill behind MSE walls should consist of structural or general grade fill (Sections 2.1.4 and 2.1.5, respectively).

Backfill placed adjacent to interior wall faces should consist of at least a 300 mm thick layer (measured horizontally) of 75 mm minus free-draining coarse sand and gravel similar to MOTI Bridge End Fill to create a drainage blanket and allow dissipation of groundwater from behind the MSE walls. The drainage blanket should be placed and compacted to the same standard as structural grade fill (Section 2.1.4), or to manufacturer's specifications for proprietary systems, whichever is more stringent.

A perimeter drain should be installed at the base (interior face) of the MSE wall to direct collected groundwater to the Site stormwater management system or daylighted by gravity to the surface with appropriate erosion protection at the outfall (Section 2.1.9). Depending on the gradation variance between the backfill and drainage blanket materials, non-woven geotextile filter cloth (such as Nilex 4551, or approved equivalent) should be placed between the drainage blanket and backfill to prevent the migration of fines from the backfill into the drainage blanket that may foul the perimeter drain.

2.4.2 Frost Protection

Based on the selected freezing index for the Site (Section 2.1.1), it is recommended that MSE walls be embedded to a minimum of 1.5 mbgs for frost protection purposes. Subject to the review of a geotechnical engineer, subgrade soils prone to frost heave may be sub-excavated and replaced with structural grade fill (Section 2.1.4) to reduce embedment depth.

2.4.3 Lateral Earth Pressure Coefficient

At rest (k_o), active (k_a), and passive (k_p) lateral earth pressure coefficients were calculated for backfill materials consisting of structural grade fill (Section 2.1.4), general grade fill (Section 2.1.5) and granular deposits encountered during the investigation. Table 6 outlines parameters which may be used for backfill materials for design purposes.

Table 6: Lateral Earth Pressure Coefficients

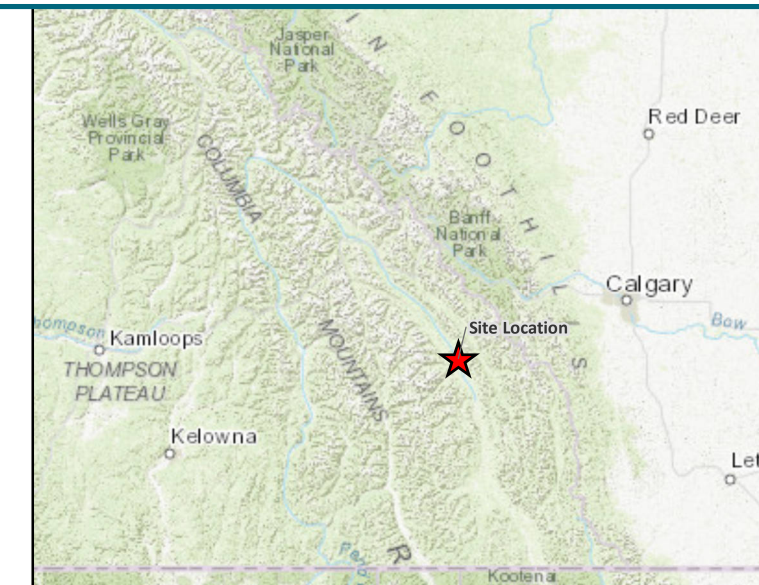
Backfill Material	Inferred Internal Angle of Shear Resistance (°)	k_o	k_a	k_p
General Grade Fill	33	0.46	0.29	3.39
Structural Grade Fill	34	0.44	0.28	3.54
Sand with Gravel	32	0.47	0.31	3.25
Silty Sand with Gravel	30	0.50	0.33	3.00
Gravel with Sand	34	0.44	0.28	3.54
Gravel with Silt and Sand	33	0.46	0.29	3.39
Silty Gravel with Sand (Till)	36	0.41	0.26	3.85

2.4.4 Global Stability

Assessment of global stability for MSE walls has not been performed as design criteria (e.g., height, width and foundation bearing type and depth) has not yet been determined. Upon request, following the determination of the required design criteria, SNC-Lavalin can conduct this assessment. Based on subsurface conditions encountered, it is unlikely that global stability will be a major risk for the project given that the loading of the proposed wildlife crossing is likely similar to loading at the Site prior to highway construction that cut through the ridgeline.

Drawing

- 680927-001 – Location Plan



Legend

- ★ Proposed Crossing Locations
- ★ Site Location

Notes:
1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale; however, scale bar will remain accurate.
3. Intended for illustration purposes. Accuracy has not been verified for construction or navigation purposes.

References:
1. Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community
2. BCGOV ILMB Crown Registry and Geographic Base Branch (CRGB)

Revisons:
0 - AO - 2021-06-28 - DRAFT - SC
1 - AO - 2021-09-02 - FINAL - RB

0 100 200 400 600 800 1,000 Metres

Client:
Ministry of Transportation and Infrastructure

Project Location:
Highway 95/93
Near Radium, BC

SNC · LAVALIN

Location Plan

BY: AO	SCALE: 1:15,000	DATE: 2021-09-02	REF No:
CHK'D: SC	Proj Coord Sys: NAD 1983 UTM Zone 11N		680927-001

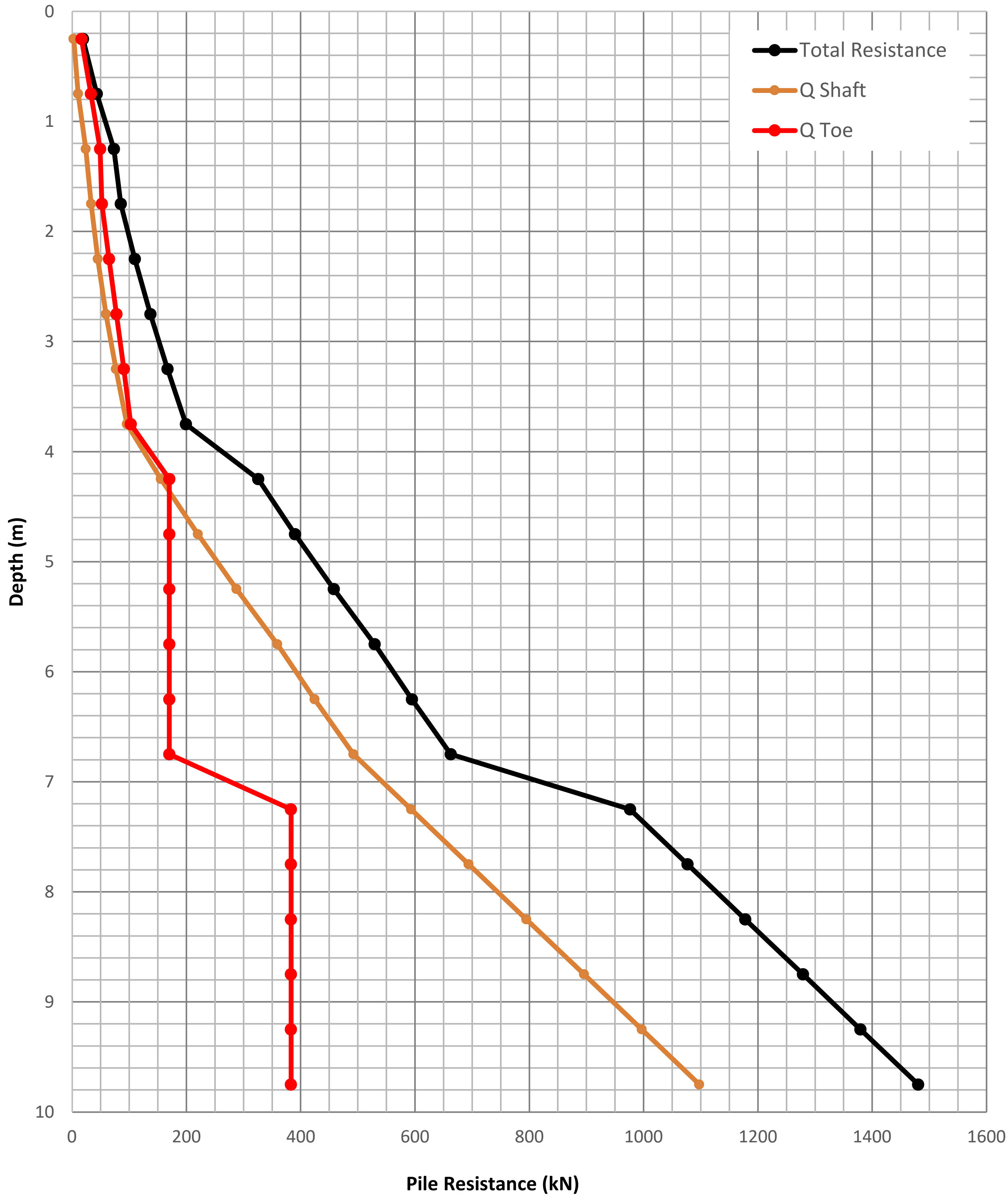
MXD Path: \\Sli2606\projects\Current Projects\Ministry of Transportation\680927 - Radium Wildlife Crossings\40_Execution\45_GIS_Dwgs\GIS\Radium-680927\680927-001-LocationPlan.mxd

Project Path: P:\Current Projects\Ministry of Transportation\680927 - Radium Wildlife Crossings\40_Execution\45_GIS_Dwgs\Exports

Appendix I

Single Pile Axial Resistance Versus Depth

Radium Wildlife Crossing - North Crossing: Current Soil Conditions (GW at 4.5 m Depth); 610 mm Open-Ended Driven Pile



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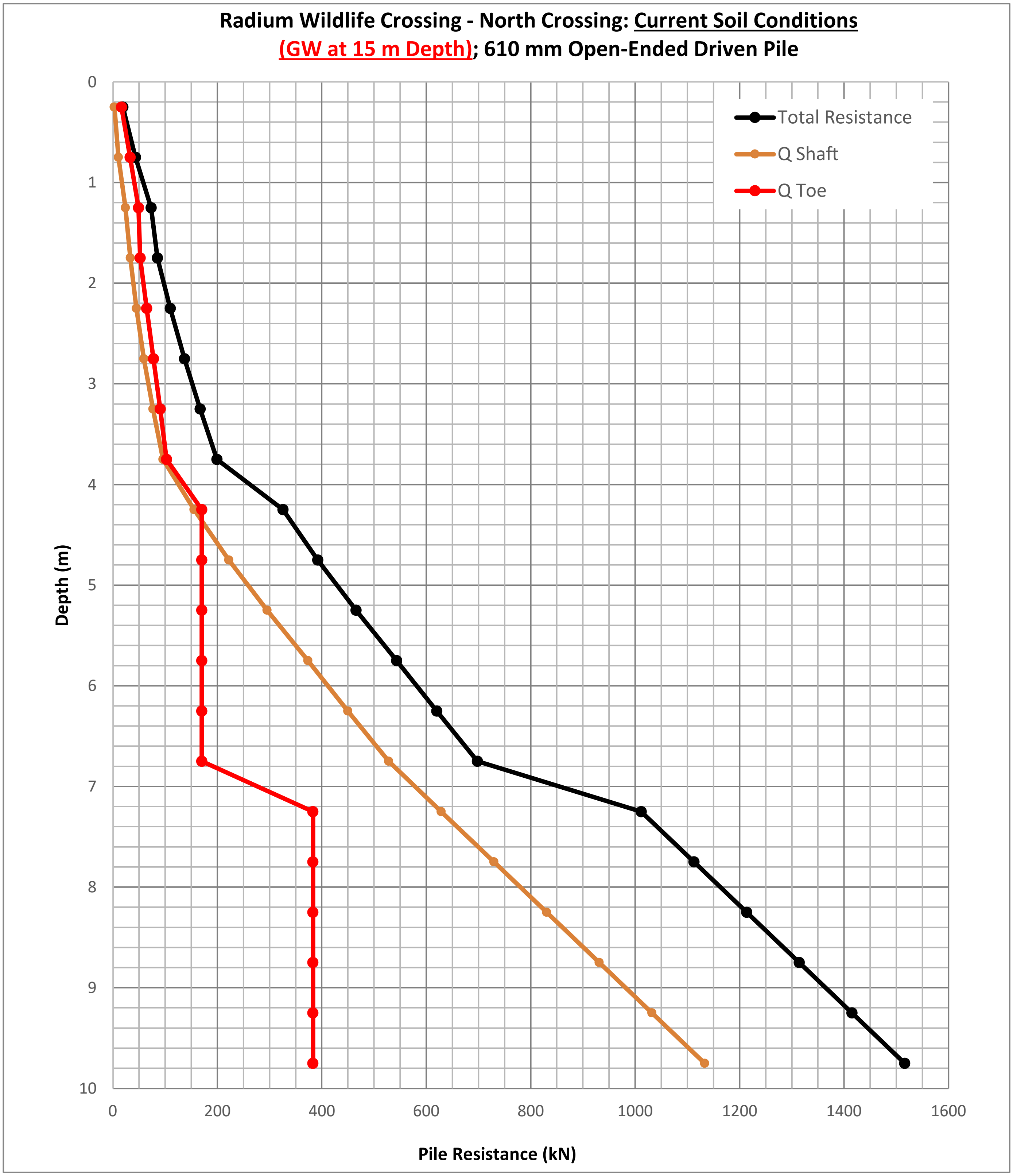
CLIENT: **MOTI**

PROJECT: **Radium Wildlife Crossing**

PROJECT NO. **680927** | DSGN. MH | CHK. SC

DATE: 2021-09-13 | SCALE: N.T.S | FIGURE:

TITLE: **Unfactored Ultimate Axial Resistance for 610mm Diameter Driven Pile**



SNC • LAVALIN	CLIENT: **MOTI**	TITLE:
	PROJECT **Radium Wildlife Crossing**	**Unfactored Ultimate Axial Resistance for 610mm Diameter Driven Pile**
	PROJECT NO. **680927** / DSGN. MH / CHK. SC	
	DATE: 2021-09-13	SCALE: N.T.S / FIGURE:

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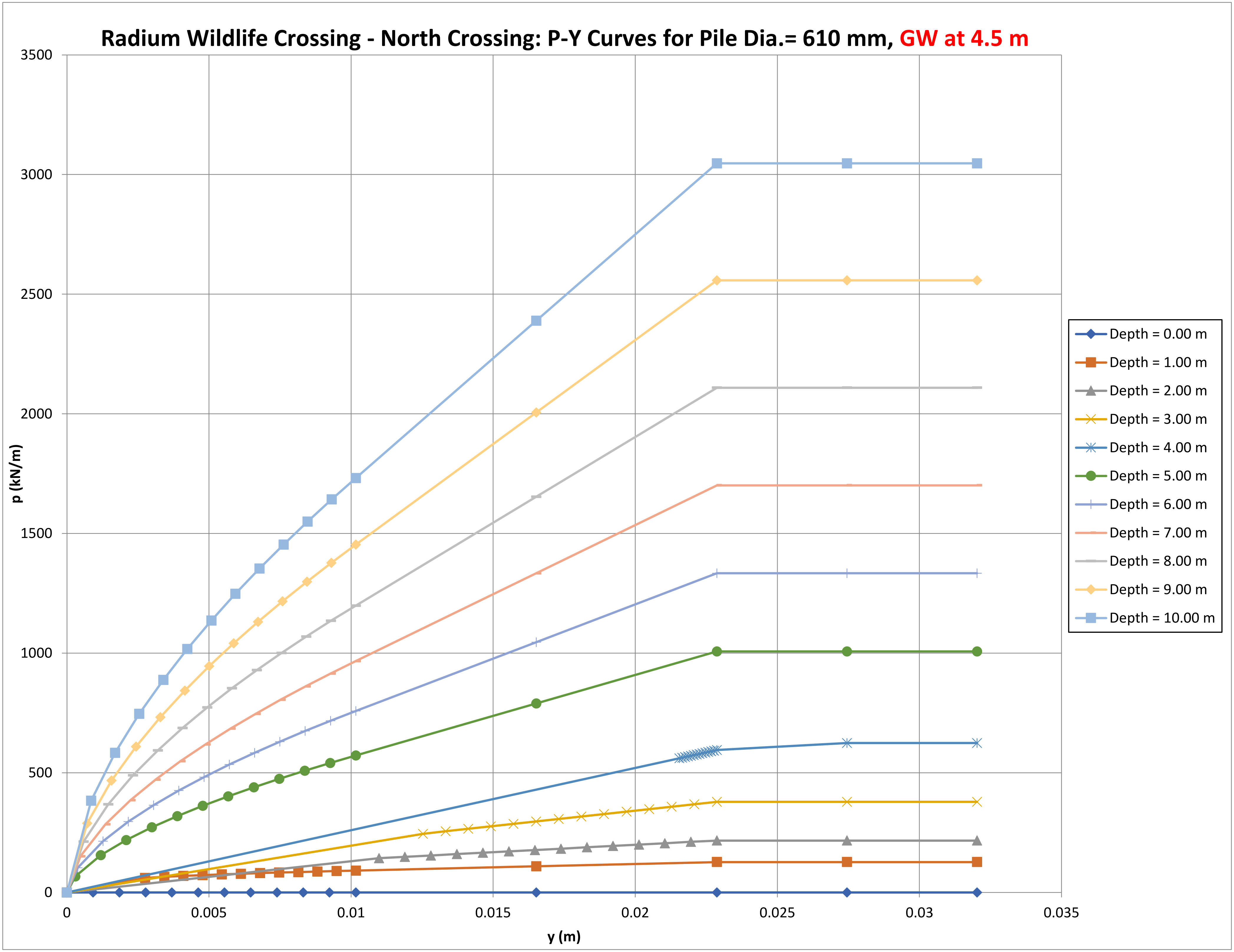
Appendix II

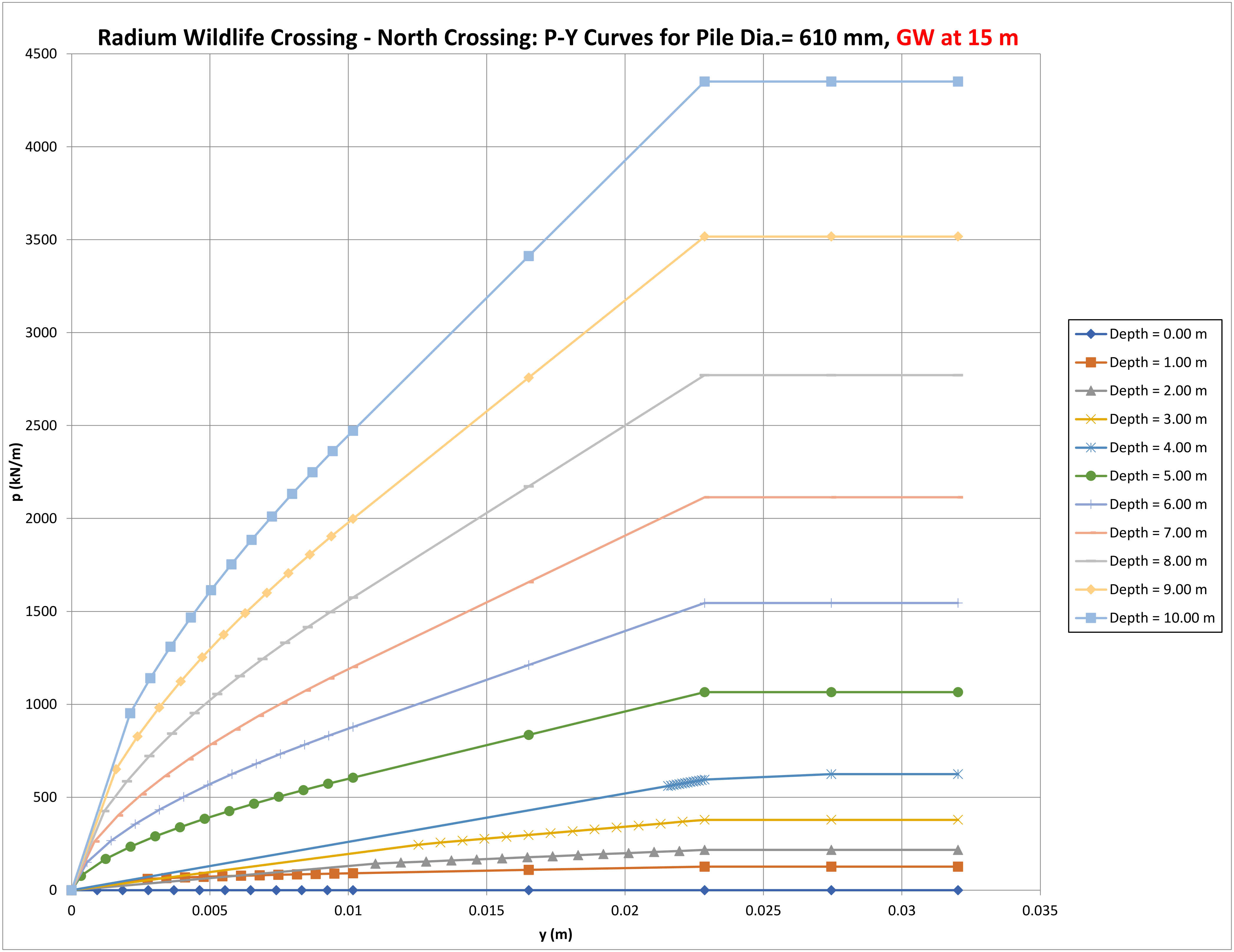
Pile Lateral Response Analysis (P-Y Curves)


Radium Wildlife Crossing - North Crossing: P-Y Curves for Pile Dia.= 610 mm, GW at 4.5 m
p (kN/m)
y (m)
0
500
1000
1500
2000
2500
3000
3500
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
Depth = 0.00 m
Depth = 1.00 m
Depth = 2.00 m
Depth = 3.00 m
Depth = 4.00 m
Depth = 5.00 m
Depth = 6.00 m
Depth = 7.00 m
Depth = 8.00 m
Depth = 9.00 m
Depth = 10.00 m

Radium Wildlife Crossing - North Crossing: P-Y Curves for Pile Dia.= 610 mm, GW at 4.5 m

Depth = 0.00 m		Depth = 1.00 m		Depth = 2.00 m		Depth = 3.00 m		Depth = 4.00 m		Depth = 5.00 m	
y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)
0	0	0	0	0	0	0	0	0	0	0	0
0.000	0.000	0.003	60.587	0.011	142.762	0.013	244.385	0.022	560.299	0.000	66.709
0.001	0.000	0.003	64.887	0.012	148.555	0.013	255.881	0.022	562.949	0.001	155.588
0.002	0.000	0.004	68.640	0.013	154.243	0.014	266.119	0.022	565.599	0.002	218.772
0.003	0.000	0.005	71.989	0.014	159.930	0.015	276.357	0.022	568.249	0.003	271.813
0.004	0.000	0.005	75.029	0.015	165.618	0.016	286.596	0.022	570.899	0.004	318.861
0.005	0.000	0.006	77.819	0.016	171.305	0.017	296.834	0.022	573.550	0.005	361.795
0.006	0.000	0.007	80.407	0.016	176.993	0.017	307.073	0.022	576.200	0.006	401.663
0.006	0.000	0.007	82.823	0.017	182.680	0.018	317.311	0.022	578.850	0.007	439.127
0.007	0.000	0.008	85.094	0.018	188.368	0.019	327.550	0.022	581.500	0.007	474.632
0.008	0.000	0.009	87.240	0.019	194.055	0.020	337.788	0.022	584.150	0.008	508.500
0.009	0.000	0.009	89.276	0.020	199.742	0.020	348.027	0.023	586.800	0.009	540.972
0.010	0.000	0.010	91.214	0.021	205.430	0.021	358.265	0.023	589.450	0.010	572.233
0.017	0.000	0.017	109.072	0.022	211.117	0.022	368.504	0.023	592.100	0.017	789.681
0.023	0.000	0.023	126.930	0.023	216.805	0.023	378.742	0.023	594.750	0.023	1007.130
0.027	0.000	0.027	126.930	0.027	216.805	0.027	378.742	0.027	624.542	0.027	1007.130
0.032	0.000	0.032	126.930	0.032	216.805	0.032	378.742	0.032	624.542	0.032	1007.130

Depth = 6.00 m		Depth = 7.00 m		Depth = 8.00 m		Depth = 9.00 m		Depth = 10.00 m	
y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)
0	0	0	0	0	0	0	0	0	0
0.000	102.964	0.000	150.779	0.001	212.094	0.001	288.957	0.001	383.507
0.001	214.066	0.001	284.417	0.001	368.237	0.002	467.267	0.002	583.379
0.002	295.564	0.002	385.342	0.002	489.376	0.002	609.074	0.003	745.986
0.003	364.505	0.003	471.411	0.003	593.556	0.003	732.089	0.003	888.283
0.004	425.873	0.004	548.325	0.004	687.048	0.004	842.977	0.004	1017.156
0.005	481.992	0.005	618.822	0.005	772.956	0.005	945.149	0.005	1136.248
0.006	534.175	0.006	684.475	0.006	853.097	0.006	1040.639	0.006	1247.774
0.007	583.257	0.007	746.293	0.007	928.648	0.007	1130.781	0.007	1353.208
0.007	629.807	0.008	804.970	0.008	1000.425	0.008	1216.507	0.008	1453.589
0.008	674.236	0.008	861.009	0.008	1069.024	0.008	1298.501	0.008	1549.685
0.009	716.851	0.009	914.787	0.009	1134.893	0.009	1377.284	0.009	1642.081
0.010	757.892	0.010	966.599	0.010	1198.384	0.010	1453.261	0.010	1731.239
0.017	1045.890	0.017	1333.907	0.017	1653.770	0.017	2005.500	0.017	2389.110
0.023	1333.889	0.023	1701.215	0.023	2109.156	0.023	2557.739	0.023	3046.981
0.027	1333.889	0.027	1701.215	0.027	2109.156	0.027	2557.739	0.027	3046.981
0.032	1333.889	0.032	1701.215	0.032	2109.156	0.032	2557.739	0.032	3046.981



Radium Wildlife Crossing - North Crossing: P-Y Curves for Pile Dia.= 610 mm, GW at 15 m
p (kN/m)
y (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
Depth = 0.00 m
Depth = 1.00 m
Depth = 2.00 m
Depth = 3.00 m
Depth = 4.00 m
Depth = 5.00 m
Depth = 6.00 m
Depth = 7.00 m
Depth = 8.00 m
Depth = 9.00 m
Depth = 10.00 m

Radium Wildlife Crossing - North Crossing: P-Y Curves for Pile Dia.= 610 mm, GW at 15 m

Depth = 0.00 m		Depth = 1.00 m		Depth = 2.00 m		Depth = 3.00 m		Depth = 4.00 m		Depth = 5.00 m	
y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)
0	0	0	0	0	0	0	0	0	0	0	0
0.000	0.000	0.003	60.587	0.011	142.762	0.013	244.385	0.022	560.299	0.000	77.054
0.001	0.000	0.003	64.887	0.012	148.555	0.013	255.881	0.022	562.949	0.001	168.115
0.002	0.000	0.004	68.640	0.013	154.243	0.014	266.119	0.022	565.599	0.002	234.014
0.003	0.000	0.005	71.989	0.014	159.930	0.015	276.357	0.022	568.249	0.003	289.569
0.004	0.000	0.005	75.029	0.015	165.618	0.016	286.596	0.022	570.899	0.004	338.942
0.005	0.000	0.006	77.819	0.016	171.305	0.017	296.834	0.022	573.550	0.005	384.049
0.006	0.000	0.007	80.407	0.016	176.993	0.017	307.073	0.022	576.200	0.006	425.966
0.006	0.000	0.007	82.823	0.017	182.680	0.018	317.311	0.022	578.850	0.007	465.375
0.007	0.000	0.008	85.094	0.018	188.368	0.019	327.550	0.022	581.500	0.007	502.739
0.008	0.000	0.009	87.240	0.019	194.055	0.020	337.788	0.022	584.150	0.008	538.391
0.009	0.000	0.009	89.276	0.020	199.742	0.020	348.027	0.023	586.800	0.009	572.581
0.010	0.000	0.010	91.214	0.021	205.430	0.021	358.265	0.023	589.450	0.010	605.502
0.017	0.000	0.017	109.072	0.022	211.117	0.022	368.504	0.023	592.100	0.017	835.593
0.023	0.000	0.023	126.930	0.023	216.805	0.023	378.742	0.023	594.750	0.023	1065.684
0.027	0.000	0.027	126.930	0.027	216.805	0.027	378.742	0.027	624.542	0.027	1065.684
0.032	0.000	0.032	126.930	0.032	216.805	0.032	378.742	0.032	624.542	0.032	1065.684

Depth = 6.00 m		Depth = 7.00 m		Depth = 8.00 m		Depth = 9.00 m		Depth = 10.00 m	
y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)	y (m)	p (kN/m)
0	0	0	0	0	0	0	0	0	0
0.001	149.936	0.001	262.474	0.001	425.584	0.002	651.097	0.002	951.701
0.001	266.378	0.002	402.269	0.002	585.709	0.002	827.707	0.003	1140.200
0.002	356.025	0.003	515.676	0.003	721.348	0.003	982.678	0.004	1310.393
0.003	432.930	0.003	614.804	0.004	842.168	0.004	1123.239	0.004	1467.366
0.004	501.858	0.004	704.524	0.004	952.694	0.005	1253.255	0.005	1614.174
0.005	565.146	0.005	787.403	0.005	1055.495	0.005	1375.091	0.006	1752.829
0.006	624.155	0.006	864.995	0.006	1152.204	0.006	1490.327	0.007	1884.741
0.007	679.764	0.007	938.335	0.007	1243.937	0.007	1600.079	0.007	2010.948
0.008	732.580	0.008	1008.149	0.008	1331.498	0.008	1705.177	0.008	2132.241
0.008	783.047	0.008	1074.974	0.009	1415.493	0.009	1806.252	0.009	2249.238
0.009	831.498	0.009	1139.221	0.009	1496.390	0.009	1903.804	0.009	2362.435
0.010	878.192	0.010	1201.211	0.010	1574.558	0.010	1998.234	0.010	2472.237
0.017	1211.905	0.017	1657.671	0.017	2172.890	0.017	2757.562	0.017	3411.687
0.023	1545.618	0.023	2114.131	0.023	2771.223	0.023	3516.891	0.023	4351.136
0.027	1545.618	0.027	2114.131	0.027	2771.223	0.027	3516.891	0.027	4351.136
0.032	1545.618	0.032	2114.131	0.032	2771.223	0.032	3516.891	0.032	4351.136

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