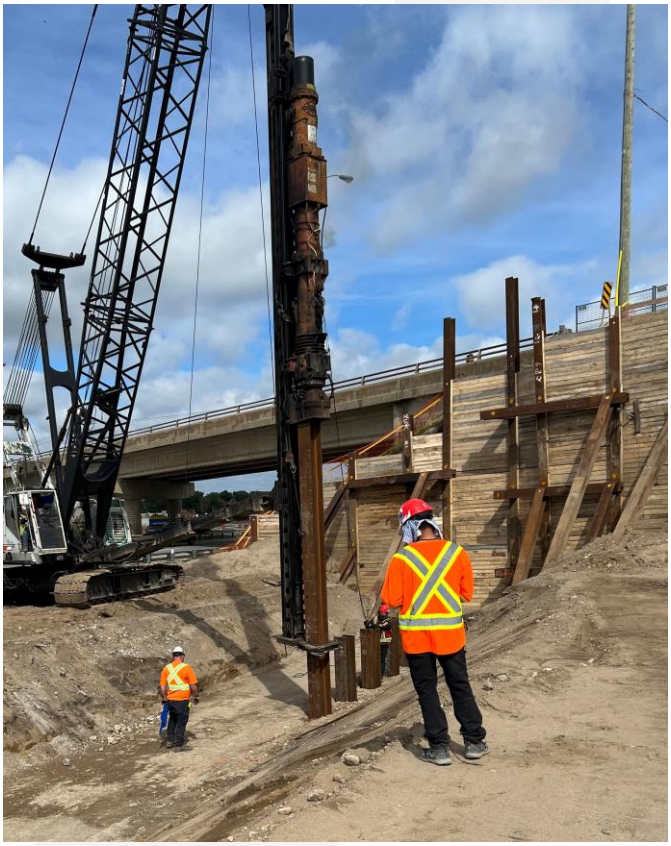
Research Report

Controlling the Installation of Driven Piles

Assignment No. 5018-E-0012
Work Item No.15



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Executive Summary

Piles are structural members that are utilized to transfer structural loads to deeper and stronger soil strata where adequate support is available. Pile materials, the degree of ground disturbance caused by installation, and transfer mechanisms are commonly used to classify piles. Loads are transferred either through the distribution of the load along the pile shaft or through the use of the pile tip to transfer the load to a strong layer with good bearing capacity. In many instances, the load is transferred through a combination of skin friction and end bearing. Piles that utilize the shaft to transfer the structural loads are called "friction piles," while those that utilize the pile tip are called "end bearing piles". The soil profile, its density and shear strength and the pile characteristics determine the relative contributions. The structural capacity is the load that the pile unit can support as a structural member, determined in accordance with the National Building Code (NBC), and Canadian Highway Bridge Design codes (CHBDC). In cases such as piles founded on hard rock, the structural capacity forms the basis of design axial capacity, but geotechnical considerations typically govern the bearing capacity of a pile.

Predictive models to estimate developed pile capacity include static analyses using theoretical formulae, dynamic formulae (Hiley, Engineering News Record, Gates, and their various modifications) using actual driving operations and hammer-rated energy input, Wave-Equation Analyses to Dynamic Monitoring with the Pile Driving Analyzer (PDA) using Case Method Estimate and the more accurate computer signal matching approach (CAPWAP), and conventional static load tests. The MTO employs a customized version of the Hiley Dynamic Formula on many/most of its projects to control pilling installation and to verify the developed geotechnical axial capacity of the pile during installation and on restrike. The accuracy of the MTO Modified Hiley Dynamic Formula has been challenged on MTO projects. Further, the inconsistency of the MTO Modified Hiley Dynamic Formula from pile to pile and from site to site has led to discussions regarding the validity of the application of the formula on MTO projects. These discussions culminated with the decision by MTO to introduce dynamic analyses on provincial projects and the initiation of studies to address the strategy for best use.

The purpose of this study is focused on the assessment of the MTO data base supplemented by data from EXP projects to compare PDA and the MTO modified Hiley Formula in controlling the installation of driven piles. Based on this assessment, a strategy for full or partial substitution of the Hiley Formula with the PDA on MTO projects was to be developed. Efficiency, accuracy, consistency, and reproducibility, considering subsurface condition and load transfer mechanism, driving event, pile type, pile embedment, and hammer system were the key criteria on which the review and recommendations would hinge.

The basis of this study is 299 piles from 34 sites as documented herein with site-specific summaries of all relevant data. Statistical analyses were carried out to compare the PDA with the Hiley Formula and assist in the development of a strategy for the further implementation of the PDA as a policy. In assessing the data, the static load test results were set as the typical benchmark and specific data related to those tests and the general applicability were used to aid in reviewing trends and anomalies. In the absence of static load tests, a second series of analyses was carried out to show the variation of the data of both Hiley and PDA to the ultimate resistances provided in FIDR's, which are calculated mainly from static formulae informed by previous experience and related Engineering judgement. Although static formulae are not necessarily a true measurement of a pile's resistance, they can be used as benchmark target for a qualitative analysis to measure the consistency and reproducibility of Hiley and PDA measurements. This analysis would also provide insight into which test more accurately achieves the target load reported in the FIDRs. A third set of analyses were carried out to compare the Hiley measurements directly to PDA measurements to show under which conditions Hiley and PDA tests are compatible. Refining the MTO Hiley for possible improved application was not part of the mandate.

In summary, the study infers that the MTO Hiley Formula cannot be generally relied upon to predict a pile's ultimate capacity with a reasonable degree of accuracy and repeatability; quantitative agreement, where it occurs, is primarily coincidental. In specific local areas and particular cases (Friction piles in cohesionless soils), Hiley results are/can be close to the real value of the static capacity of the pile and ultimate geotechnical capacity provided by FIDR; when used in these settings and by competent individuals; this can serve to enhance engineering judgement. In other cases [steel piles driven by drop hammer (based on limited data for hammer energy of 80 kJ), and for piles driven with Delmag diesel hammers], Hiley results are close to the PDA results; this can serve to enhance engineering judgement. However, considering the viable alternatives available, continued general and wide-spread use in most cases, is not recommended; an approach using the

easy to perform wave equation analysis coupled with dynamic monitoring with the PDA and CAPWAP treatment of the data is indicated as the best way forward to control pilling installation. Static load testing should be used on large scale complex sites where schedule permits, to optimize designs. The findings were examined in the context of other previous studies using mainly Canadian and American data and the results were found to be similar.

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1. Introduction

The MTO Provincial Highway Management (PHM) division's top priorities are to invest in research and development that directly contributes to the sustainability of Ontario's infrastructure and to update its technical standards. MTO goal to maintain and develop expertise is evidenced by the commissioning of this study. EXP Services Inc. (EXP) was retained by the Ministry of Transport Ontario (MTO) to provide a detailed comparison of the estimated developed pile capacity generated by the Ministry's Modified Hiley Formula versus those obtained by the Pile Driving Analyzer (PDA). To meet the requirements of the Terms of Reference of this assignment, a strategy for the implementation of the PDA as a full or partial substitution for the Hiley Formula based on criteria including the efficiency, accuracy, consistency, and reproducibility considering the pile hammer system, pile type, embedment depth and subsurface conditions was to be developed.

A total of 65 sites encompassing 700+ events were available for review of which 12 sites representing 54 events were provided by EXP. However, after detailed examination of the data sets for completeness, a total of 34 sites representing 299 testing events were used for analysis in this assignment as the remaining 31 sites lacked either Hiley and/or PDA information. Each of the 34 sites were comprehensively summarized and is presented in Table 1 in section 4 of this report. Figure 1(A) shows a breakdown of all the data provided by MTO and EXP and what information was available in terms of the number of each test, while Figure 1(B) shows a breakdown of the final data set that was used in this project. A site map, showing the locations of the sites is provided in Figure 2 in section 4. Limitations in available data, precluded development and support of meaningful conclusions on a few issues, notably impacts from the full range of hammer systems; where this occurs, general comments are provided using data available and support from the literature.

To achieve the objectives of this assignment, it was imperative in establishing benchmarks on which the accuracy of results obtained from both the Modified Hiley and PDA tests could be evaluated. As such, the static pile load test, considered the most accurate predictor of a pile's capacity, was used to assess accuracy where available. In the absence of a static pile load tests, assessments were made based on the ultimate geotechnical resistances proposed in the Foundation Investigation and Design Reports (FIDR). Statistical metrics were then employed as the primary means of assessing the accuracy and precision of the results.

2. Background

The modified Hiley formula is the main pile drive control tool used by the MTO for years. MTO considers the modified Hiley formula as a monitoring tool (MTO 2016), not a design tool. The MTO employs the modified Hiley Formula on its projects to control pile installation and to verify the axial capacity of piles during installation and on restrike. The accuracy of the MTO Hiley Formula has been challenged on MTO projects by various stakeholders with calls to implement the use of a more accurate prediction method. In addition, the inconsistency of results produced due to the application of the MTO's Modified Hiley Formula from both pile to pile and site to site has led to discussions regarding the validity of applying the formula on MTO projects. These discussions culminated with the proposal to introduce the use of the PDA on MTO projects as a partial or full substitution for the currently utilized Modified Hiley Formula. However, before any recommendation(s) can be made as to the use of the PDA as a more suitable means of assessing developed pile capacities, it is imperative that the behaviour and limitations of the Modified Hiley Formula be defined quantitatively. This quantitative assessment includes but is not limited to the type of hammers used during installation, the soil stratigraphy encountered, the type of piles used during installation and the event type being assessed. Moreover, a quantitative assessment of the afore-mentioned factors as it also relates to the behaviour and limitations of the proposed PDA must also be fully understood. Findings resulting as a product of a detailed comparison between analyzed data from both the use of the Modified Hiley Formula and the PDA would serve as a basis for suitable recommendations to be made. While not specifically included in the scope of this work, the economic implications (costs and benefits) are integral to the assessment of the proposed policy advancement. These include such considerations of any additional costs for monitoring, and potential savings in optimizing designs under Limit State Designs (LSD) based on Load and Resistance factors (LRFD), while maintaining the appropriate level of safety.

3. Pile Driving Control in Canadian Jurisdictions

Pile driving control is utilized in the field to monitor pile installations and, as a result, to give some confidence regarding the validity of design assumptions. Across Canada, Canadian provinces adopt different techniques to monitor piles during and after driving. As part of the review, the practices of Pile driving monitoring of Provinces across Canada were reviewed to establish their preferred approach for specific settings. In Ontario, MTO currently uses the modified Hiley Formula coupled with some levels of dynamic monitoring. Based on the MTO Structural Manual (2016), the modified Hiley formula is used as a pile driving control tool (i.e., as a monitoring tool, not a design tool) for frictional piles in cohesionless soils. In addition, most of the other provinces (i.e., Alberta, British Columbia, New Brunswick and Newfoundland and Labrador) are currently utilizing dynamic monitoring for piles. The practices of pile driving monitoring in some Canadian provinces are reviewed in this section.

Alberta Transportation (2020) adopts both static load testing and High Strain Dynamic Load Testing - Pile Driving Analysis (PDA Testing) for the testing of piles. As stated in the Contract agreements, static load testing and reporting must be carried out in accordance with ASTM D1143/D1143M for piles subjected to axial compressive loads and ASTM D3689/D3689M for piles subjected to axial tensile loads. The ASTM D4945 standard must be followed when conducting PDA testing. According to Alberta Transportation (2020), the consultant is required to assess the remaining piles, and based on the results of the PDA testing, may change the requirement that have been set and the tip elevation requirements. The Associated Engineering for the Government of the Northwest Territories (2021) has adopted the same standards.

Department of Transportation and Infrastructure, New Brunswick (2019) mentioned that contractors are required to dynamically test the piles during driving to measure and estimate mobilized resistance, hammer performance, pile stress, and soil dynamic properties at the conclusion of initial driving and during all retaps (restrike). AASHTO T298-99 must be followed when conducting the tests. The acceptability criteria for the pile shall be established considering the findings of dynamic testing and analysis.

Ministry of Transportation and Infrastructure, BC (2022) in Table 6.2a (benchmarks for the degree of understanding for deep foundations) requires that the pile designs for bridge piers must be based on a single test pile in accordance with ASTMD1143. Borehole, CPT, or BPT data can be used to extend the test results to other bridge piers. The test piles' size, and length must also be similar to the production piles' size, and length. Additionally, it requires pile dynamic testing (PDA) and dynamic analysis (CAPWAP) to be undertaken on a nearby bridge pier or abutment using pile driving blow count data collected for the pile, unless the Ministry agrees otherwise. Another option is to design a bridge pier or abutment based on a single rapid load test on a pile in accordance with ASTM D7383. Results are then extrapolated to other bridge piers and abutments by taking borehole, CPT, or BPT data into account, but the test pile size and toe condition might differ from production piles.

Department of Transportation and Infrastructure Highway Design Division, Newfoundland and Labrador (2021) require dynamic monitoring of the pile driving to confirm pile resistances, energy transfer to piles and performance of the pile-driving hammer. A Pile Driving Analyzer will be used to conduct pile tests in accordance with ASTM D4945 “High Strain Dynamic Testing of Piles”.

According to CHBDC (CSA 2019), the procedures utilized to determine a pile's ultimate geotechnical axial resistance and to verify the corresponding design depth must be suitable for the site, the ground and groundwater conditions, the type of pile, and the proposed method of installation. When necessary, at least one of the following approaches must be used:

1. Static analysis
2. Static pile load tests
3. Dynamic pile driving formulae
4. Dynamic analysis for pile installation
5. Rapid pile load tests

6. SPT and CPT based methods for estimation pile resistance
7. Assessed values

CHBDC (CSA 2019) emphasized that the use of dynamic pile driving formulae must be limited to managing pile driving operations and establishing pile driving refusal conditions. Dynamic pile driving formulae must be verified by additional methods before being utilized to calculate resistance. Moreover, it states that consideration should be made to determining a pile's static resistance by using dynamic analysis for pile installation. The driving energy transferred to the pile should be obtained so the pile can be installed to the design depth where the ultimate level of geotechnical resistance can be satisfied without causing damage to the pile. These evaluations shall consider the initial choice of the pile and the effectiveness of the pile hammer system at the site.

MTO Structural Manual (2016) uses a modified Hiley formula as pile driving control (monitoring tool, not a design tool) for frictional piles in cohesionless soils. For cohesive soils, MTO Structural Manual (2016), is not recommending the use of the Hiley formula unless the excess pore water pressure was considered by allowing it to dissipate.

4. Literature Review

The use of dynamic analysis to determine pile capacity has a history dating back to the 19th century, when a formula considering the energy of the pile driving hammer and the pile's set was developed to find its bearing capacity. Over decades, researchers found that none of the formulae were accurate and recommended instead the use of static loading tests to determine pile capacity. Today, dynamic formulae have mostly been replaced by more precise wave equation analyses and high strain dynamic testing (Likins et al. 2012).

4.1 MTO Modified Hiley Formula

MTO has been using the modified version of the Hiley formula as per SS103-11 (MTO 2016) as the means of controlling pile driving which is a simple and low-cost method of correlating ultimate soil resistance with driving resistance. The Hiley formula equates kinetic energy of the Hammer's ram to work done on the pile at the time of driving.

The MTO Modified Hiley Formula is used to estimate the resistance of a pile driven using a double-acting, differential-acting steam hammer or diesel hammer according to the following formula:

$$R = \frac{n\, e_f\, E}{S + C/2}$$

For piles driven with drop hammers and single-acting steam hammers, the pile resistance is estimated according to the following formula:

$$R = \frac{n\, e_f\, W g H}{S + C/2}$$

Where:

R = ultimate pile resistance in kilonewtons

e_f = efficiency based on manufacturer's gross rated energy (0.6 to 0.8 for steam hammers, 1.0 for diesel hammers, and 0.75 for drop hammers)

S = measured penetration of pile per hammer blow in millimeters

C = measured rebound of a pile per hammer blow in millimeters

E = rated energy of hammer blow in joules

g = acceleration due to gravity (9.80665 m/s²)

H = free fall of drop hammer mass in meters

$$n = \frac{W + Pe^2}{W + P}$$

Where:

W = mass of ram (piston) in kg

P = mass of pile + anvil or helmet in kg

e = coefficient of restitution (0.32 for steel piles where a pile driving cushion is used during driving, 0.55 for steel H-piles driven without a pile cushion, and 0.25 for timber piles.

4.2 Dynamic Testing

4.2.1 Pile Driving Analyzer

Dynamic load testing using a Pile Driving Analyzer (PDA) is a high-strain non-destructive load test method to estimate the capacity of a pile. The Pile Driving Analyzer is the most widely employed system for Dynamic load testing and pile driving monitoring. Development of dynamic testing and signal wave software matching has continued over the last 50+ years since initial work in the 1960's and 1970's at Case Western University under the direction of Professor Goble. Other similar systems were also developed in Europe at the Netherlands organization of scientific research (TNU).

The instrumentation for the PDA consists of two reusable strain gauges and two accelerometers securely bolted on the pile. For each hammer blow, electrical signals are fed into the pre-programmed PDA and the basic measurements of strain and acceleration are converted into force and velocity parameters as a function of time.

From the force and velocity parameters, the ultimate (mobilized) bearing capacities are automatically computed. In addition, the maximum compressive and tensile forces, the developed energies and the hammer blow rate, etc., are some of the outputs from the PDA. The force and velocity traces are continually observed in the field and their digital signals are recorded and stored in computer memory.

Dynamic testing of piles is undertaken in general accordance with the ASTM D4945 procedures.

4.2.2 Case Pile Wave Analysis Program (CAPWAP)

A selected representative hammer blow from the PDA test is used to perform a CAPWAP (Case Pile Wave Analysis Program) analysis to estimate the ultimate capacity of the pile and the corresponding CASE damping factors.

The CAPWAP program is an iterative method to analyze the static resistance and resistance distribution along a pile with the dynamic measures obtained from the Pile Driving Analyzer (PDA) testing. In the CAPWAP analysis, the program utilizes the fact that the force and velocity are related to each other by the pile impedance, which is readily calculable by:

$$Z = \frac{EA}{C}$$

Where Z is the impedance of the pile, E is the modulus of elasticity of the pile, A is the cross-sectional area of the pile, and C is the speed of stress wave in the pile.

In the CAPWAP program, the pile is divided into a number of mass points and springs. The soil reaction forces on these mass points are assumed to consist of elastoplastic (static) and linear viscous (dynamic) components. In the analysis, a measured force was used as input and by varying the ultimate static resistance, resistance distribution, quake, elastic soil deformation, soil damping constants, etc., a computed force or velocity is calculated.

When a good match is obtained by varying the above components, the pile-soil interaction is modeled and a solution for the ultimate static resistance along the pile can be calculated. Based on this calculated resistance, an estimate of the frictional

resistance can also be obtained. Static computations can then be used to predict the load versus deformation characteristics of the pile, which is often referred to as a "simulated load test."

4.3 Accuracy of Dynamic Formulae in Predicting Pile Capacity

A study was performed on evaluating the capability of dynamic formulae, including the modified MTO Hiley formula, in estimating pile load capacities (Rauf and Rothenburg 2011). The results of the dynamic formulae were compared with field static pile load tests using a database comprised of 77 piles driven throughout Ontario by the MTO. Diesel hammers were used on 45 piles, which consisted of 17 concrete filled steel tube piles, 12 timber piles, 13 steel H-Piles, and 3 precast concrete piles. The remaining 32 piles were installed via drop hammer which consisted of 10 concrete filled steel tube piles, 12 timber piles, 6 steel H-Piles, and 4 precast concrete piles.

When comparing the modified MTO Hiley formula estimate with the pile load test capacities in an X-Y scatter plot, the coefficient of determination (R^2 value) was 0.0416 (~4%) for drop hammers, 0.0384 (~4%) for diesel hammers, and 0.0018 (~0.2%) when comparing all piles. The coefficient of determinations is considered very small which indicate a high level of scatter in the data points.

The ratio of Hiley to Load Test ranged from 0.156 to 2.105 with an average of 1.013 and standard deviation of 0.495 for drop hammers and ranged from 0.388 to 13.870 with an average of 2.684 and standard deviation of 2.730 for diesel hammers; the average load ratio was 1.990 with a standard deviation of 2.259 for all piles.

The percentage difference (dynamic test capacity – estimated field capacity over field estimated capacity x 100) ranged from -84.346% to 110.487% with an average of 1.329% for drop hammers and ranged from -61.241% to 1287.0% with an average value of 168.375% for diesel hammers; the average percent difference was 98.953% for all piles.

In general, the MTO modified Hiley formula tends to over-predict the actual pile capacity as measured from field pile load tests. However, when comparing the two hammer types analyzed in this study, piles installed with drop hammers produced more accurate results when considering the average of all data points. When separated by pile type, the Hiley formula tends to be most accurate for precast concrete piles, but the authors state that this may be due to the small sample size and the correlation be decrease with more data points.

Based on the results of this study, the authors do not recommend the use of the MTO modified Hiley formula in its original form due to the low correlation and large percent differences and load ratios when compared to field static load tests results (Rauf and Rothenburg, 2011).

4.4 Accuracy of PDA Testing in Predicting Pile Capacity

Likins and Rausche (2004) presented the findings of the comparison between the CAPWAP restrike test and the static load test (SLT) at the seventh stress wave conference in Orlando, Florida. The data contained the results for more than 119 driven piles and 23 cast-in-situ (including drilled shaft and auger case-CFA piles). Different interpretation techniques were employed by the authors to interpretate the ultimate capacity for the static tests. The authors performed statistical analysis to compare the results of the static tests with those of the CAPWAP. The authors found that the variations between CAPWAP and SLT results are often well within the range of SLT failure loads by the different evaluation techniques that were used and are comparable to the statistics of other static tests on the same piles. The average CAPWAP/SLT ratio was 0.98 with a coefficient of variation (COV) of 16.9%. Approximately 9% of the cases have a CAPWAP to maximum applied static load ratio exceeding a ratio of 1.1. As a result, when compared to the pile's reserve strength, CAPWAP often yields conservative results. Other studies were conducted on piles installed in intermediate geomaterial (IGM). The capacities of piles were measured using CAPWAP and static load tests. The results showed that the ratio between CAPWAP and static tests is close to unity with a low coefficient of variation (Mokwa and Brooks 2008; Verbeek et al. 2015).

In a similar report presented by the University of Illinois (Long et al. 2009), results of PDA vs Static Pile Load Tests (SPLT) were compiled and analyzed as part of a larger study which also assessed the accuracy of other dynamic formulae. The study compiled data sets that were placed into two group; the first being a collection and compilation of several smaller test

databases into one master database and the second being a collection comprising of data collected from the Wisconsin Department of Transportation. In this research, statistical metrics were used to define the performance of results. The predicted capacity QP divided by QM (Q_P/Q_M) was used to quantify the accuracy of the prediction while the Coefficient of Variation (COV) was used to quantify both the accuracy and precision of the predictive method. In the study, a value of $(Q_P/Q_M) = 1$ represented perfect agreement between predictive methods and/or SPLT while values lesser than or greater than 1 represented under and over estimations respectively. Results of the PDA based on End of Initial (EOID) showed mean values of 0.73 (Q_P/Q_M) with COV of 0.40. This indicated an underestimation in pile capacities by 27%. However, several key points were noted. Firstly, the data set consisted of 156 pile load tests of which 81 were closed end pipe piles and 13 were open ended pipe piles. In addition, 73 were driven with single acting air/steam hammers while 4 were driven with hydraulic hammers. Moreover, 16 piles were identified as unknown due to insufficient data. It was also noted that most of the pile load tests used provided results with capacities less than 750 kips (3336 kN) with average pile lengths ranging between 9 ft to 200 ft (2.74 m to 61 m). Of the vast pile load tests data presented, PDA information was only available concurrently for 20 piles of which the results were based.

In consideration of the information presented in the second database, it was reported that mean values of 0.77 (Q_P/Q_M) with COV of 0.33 were obtained. These values represent a slightly better increase in accuracy in predicting axial capacities when compared to the results obtained from the first data set. However, it was noted that a total of 12 SPLT was conducted from a total of 316 piles. Moreover, of the 12 SPLT conducted, only 3 SPLT was conducted in conjunction with PDA measurements.

In general, the study did not consider the use of the Hiley Dynamic Formula, so no comparisons were available for the accuracy of that formula. Overall, from this study, it can be concluded that the use of the PDA provided conservative estimates since it gave values that underestimates the axial capacities in the range of 23% to 27%. However, it was noted that the estimates were obtained based on data sets that were not extensive.

5. Methodology

5.1 General Overview

The main objective of this research project is to compare the PDA with the Hiley Formula and then utilize the results of the findings to develop a strategy for the implementation of the PDA as a policy. Meeting this objective will require identifying sites where both PDA and Hiley tests were completed on the same pile, reviewing all documents including contract drawings, foundation investigation and design reports, PDA testing reports, etc., extracting the required information (pile types, hammer types, subsurface conditions, etc.), and performing a statistical analysis on the data. The statistical analysis will provide justification on the appropriate method of controlling the installation of piles taking into consideration efficiency, accuracy, consistency, reproducibility. A comprehensive discussion of the methodology used to complete the project is discussed in the following sections below.

5.2 Parameters of Analysis

To better understand the correlation between the Hiley and PDA tests, the data points were compared according to different parameters to see whether Hiley and PDA tests show better or worse agreement under certain conditions. Therefore, an assessment between Hiley/PDA tests with static pile load tests, Hiley/PDA tests with pile ultimate resistances as per FIDRs, and Hiley with PDA tests was performed as a function of:

1. Pile Information
    a. Pile Type/Size (H-Pile, Pipe Pile, Precast Concrete Pile, Timber Pile)
    b. Pile Weight
    c. Embedment Length
    d. Whether a Driving Shoe/Bearing Point was used

   e. Whether the pile was spliced

2. Pile Driving Information
   a. Crane, Excavator, Etc.
   b. Pile Driving Lead (Fixed vs. Swinging)

3. Hammer System
   a. Type (Diesel, Hydraulic, or Drop Hammer)
   b. Weight of Ram/Piston
   c. Weight of Anvil
   d. Whether a Cushion was used
   e. Hammer Rated Energy

4. Subsurface Conditions
   a. End bearing strata (cohesionless, cohesive, bedrock)
   b. Skin Friction Bearing Strata (cohesionless, cohesive, layered)

5. Pile Driving Resistance
   a. Low blows per inch (less than 2 blows per 25 mm)
   b. High blows per inch (more than 8 blows per 25 mm)
   c. Intermediate blows per inch (between 2 and 8 blows per 25 mm)

6. Pile Driving Event
   a. End of Initial Drive
   b. Beginning of Restrike

5.3 Work Program Overview

The work program compares the Hiley Formula and the PDA, summarizes the results of the study, and presents recommendations and guidelines on the preferred method of controlling the installation of driven piles. This includes:

1. Identification of projects where both PDA and Hiley Formula were applied on the same project, collection of pile load tests report and consideration of projects from MTO and EXP's databases
2. Review of pile installation summary reports, pile installation logs, PDA reports, or unsorted logs as provided
3. Compilation of required data for each Hiley/PDA test including the test results and all required details used as parameters of the analyses as stated in the terms of reference and summarized in Section 4.2 of this report. A summary of static pile load tests was included as well to aid in the assessment
4. Verification of the Hiley calculations done in the field to ensure accuracy through re-calculations as was necessary
5. Assessment of subsurface conditions and load transfer mechanism for each pile
6. Performing statistical analysis as a function of the parameters in Section 4.2 for:
   a. Hiley and PDA tests vs. Static Pile Load Tests (where available)
   b. Hiley and PDA tests vs. Ultimate Resistance as per FIDR's
   c. Hiley vs. PDA test
7. Provide a discussion that summarizes key points of the results and any trends that were identified
8. Develop conclusions and recommendations based on the results and discussion

5.4 Data Acquisition

Documents were provided to EXP from MTO for a total of 53 sites. These documents included: contract drawings, Foundation Investigation and Design Reports (FIDR), pile driving summaries and pile driving logs, PDA testing reports, site visit field logs, as-built reports and memos, and static pile load test reports. From the 53 sites provided by MTO, 47 sites contained PDA tests and 25 contained Hiley tests, with 22 sites containing both PDA and Hiley tests performed for the same piles. In addition, static pile load tests reports were available for 5 of those 22 sites.

EXP provided an additional 12 sites where both PDA and Hiley tests were performed on the same piles. One pile load test report was available from those 12 sites. In all, the total amount of sites obtained (MTO and EXP sites) was 65.

After comprehensive reviews of the available sites for suitability and completeness, 34 sites were selected for analysis, with 6 of these sites containing pile load tests performed on a total of 18 piles. The total number of data points (piles with both PDA and Hiley performed on the same pile) was 299. Figure 1(A) shows a breakdown of all the data provided by MTO and EXP and what information was available in terms of the number of each test, while Figure 1(B) shows a breakdown of the final data set that was used in this project. A site map containing the location of all 34 sites is shown in Figure 2.

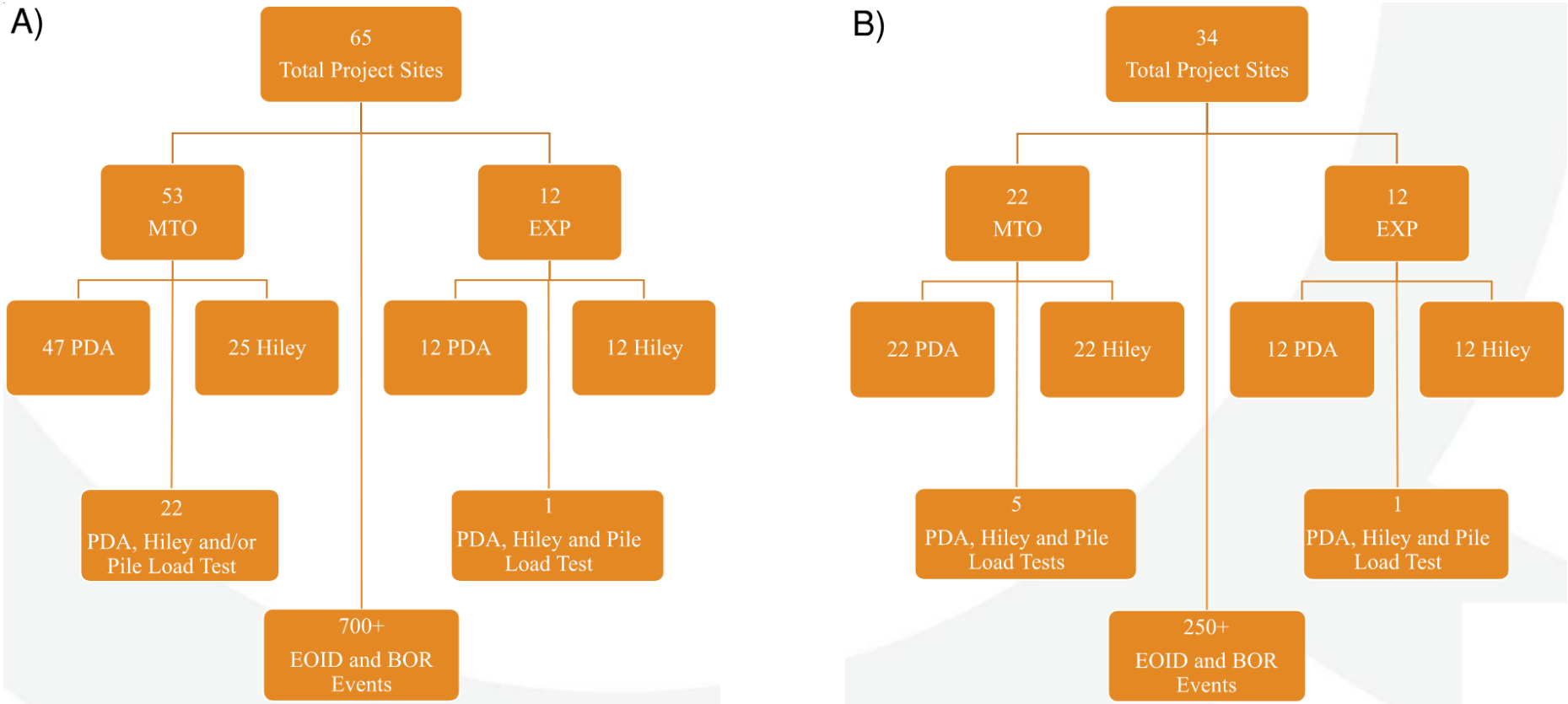
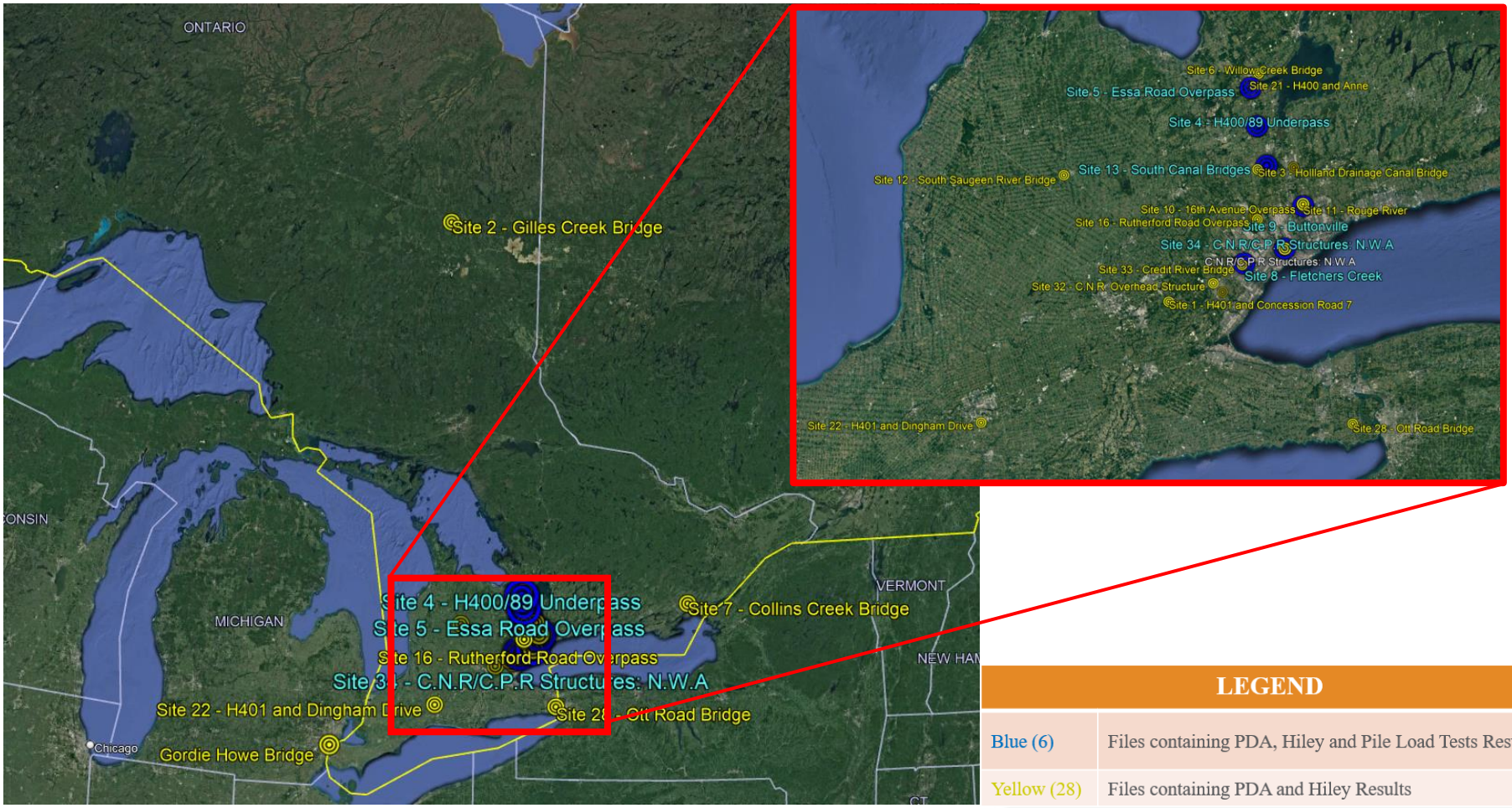


Figure 1 - (A) Summary of total site data provided by MTO and EXP, (B) Summary of site data with complete sets of data used for this project



LEGEND	
Blue (6)	Files containing PDA, Hiley and Pile Load Tests Results
Yellow (28)	Files containing PDA and Hiley Results

Figure 2 - Site Map Showing Sites with PDA and Hiley Test Data (Yellow) and PDA, Hiley, and Pile Load Test Data (Blue)

5.5 Data Compilation

Once the data sets were acquired and reviewed, a master database was created for each data point where a Hiley and PDA test was performed on the same pile. The database included the ultimate resistance estimated for each pile with both tests, along with details of all the parameters highlighted in Section 3.2 of this report (Pile information, pile driving information, hammer system information, subsurface conditions/load transfer mechanism, pile driving resistance, pile driving event, and CAPWAP results if available).

A condensed summary of this database is presented in Table 1 below which includes the site number, project name, pile type, number of tests per project, hammer type (diesel, hydraulic, etc.), soil strata, and load-transfer mechanism. Note that a site map of the location of each site is presented in Figure 2 on the previous page.

An individual report was created for each of the 34 sites with data summarized from the master database. These individual reports also provided a basic site map showing the location of the tests, a drawing of the subsurface conditions at each of the pile locations taken from the FIDRs, and a list of sources for all the document from which the data was extracted (contract drawings, FIDRs, PDA reports, etc.).

Where static pile load tests were performed, each separate report provided a summary of the test including the purpose of the tests, the specific pile load testing method applied, the failure criterion for establishing the pile's ultimate resistance, the reason for terminating the test, and the load-displacement curves. A compilation of these reports is provided in Appendix B.

Table 1 - Summary of Pile Database Used in Study

Site #	Project	# of Tests	Pile Type	Hammer Type	Soil Strata	*Load-Transfer Mechanism
1	Replacement of Underpass at Highway 401 and Concession Road 7	3	HP310 x 110	Diesel	Cohesionless	End Bearing
2	Hwy 579 - Gilles Creek Bridge Replacement	11	HP310 x 110	Diesel	Cohesionless	End Bearing
3	Hwy 9 - Holland Drainage Canal Bridge Replacement	7	HP310 x 79	Diesel	Cohesive	Friction
		2	Pipe Pile		Cohesive	Friction
4	Highway 400/89 Underpass Replacement	10	HP310 x 110	Diesel	Cohesionless	End Bearing
		1			Cohesive	End Bearing
		2			Layered/Cohesionless	Friction/End Bearing
		10			Layered/Cohesive	Friction/End Bearing
5	Essa Road Overpass, Highway 400 Widening	2	HP310 x 110	Hydraulic	Cohesionless	End Bearing
6	Willow Creek Bridge Replacement	1	HP310 x 110	Diesel	Cohesionless	End Bearing
7	Collins Creek Bridge	10	HP310 x 110 (HP12 x 74)	Diesel	Cohesionless	End Bearing
		6			Cohesionless	Friction
		5			Cohesionless	Friction/End Bearing
8	Fletcher's Creek Bridges, Highway 401 Widening	1	HP310 x 110	Diesel	Cohesionless	End Bearing
9	Twin Overpass Structures at the Crossing of Hwy. #404 and 16th Avenue (Buttonville)	1	HP310 x 110 (HP12 x 74)	Diesel	Cohesionless	End Bearing
		1	Pipe Pile		Cohesionless	End Bearing
		1	Precast Conc.		Cohesionless	End Bearing
		1	Precast Conc.		Layered	Friction
		1	Timber		Layered	Friction
10	Hwy 404 HOV Lane Expansion & Rehab (16th Avenue)	5	HP310 x 110	Diesel	Cohesionless	End Bearing
		4			Cohesive	End Bearing
		8			Cohesive	Friction
		3			Layered	Friction
		4		Drop	Cohesionless	End Bearing
11	Hwy 404 HOV Lane Expansion & Rehab (Rouge River)	12	HP360 x 174	Diesel	Cohesive	End Bearing
		6		Drop	Cohesive	End Bearing
12	South Saugeen River Bridge Replacement, Highway 89	3	HP310 x 110 (HP12 x 74)	Diesel	Cohesionless	Friction/End Bearing
		1			Cohesionless	End Bearing

Site #	Project	# of Tests	Pile Type	Hammer Type	Soil Strata	*Load-Transfer Mechanism
		2			Cohesive	End Bearing
13	Hwy 400 South Canal Bridges	10	HP310 x 110	Diesel	Cohesionless	End Bearing
		9			Cohesive	End Bearing
		6			Cohesive	Friction
		3			Layered	Friction
		3		Hydraulic	Cohesionless	End Bearing
14	Hwy 427 over Rainbow Creek	11	HP360 x 174	Diesel	Cohesionless	End Bearing
		11			Cohesive	End Bearing
15	Langstaff Road Underpass - Highway 427 Expansion	10	HP360 x 174	Diesel	Bedrock	End Bearing
16	Hwy 427 over Rutherford Rd.	3	HP360 x 174	Diesel	Cohesive	Friction/End Bearing
		3			Cohesive/Cohesionless	Friction/End Bearing
17	Hwy 427 over West Robinson Creek	12	HP310 x 110	Diesel	Cohesive	End Bearing
18	Hwy 427 - CPR at McGillivray Rd	2	HP310 x 110	Diesel	Cohesionless	End Bearing
		3	HP360 x 174		Cohesionless	End Bearing
		2			Layered/Cohesionless	Friction/End Bearing
19	Major Mackenzie Drive Overpass (Structure B18)	2	HP310 x 110	Diesel	Cohesive	End Bearing
20	Major Mackenzie Drive Over West Robinson Creek	3	HP310 x 110	Diesel	Cohesionless	End Bearing
		5			Cohesionless	Friction/End Bearing
21	Hwy 400 - Anne Street Underpass	11	HP310 x 110	Diesel	Layered	Friction
		3			Layered/Cohesive	Friction/End Bearing
22	Highway 401 & Dingham Drive Underpass	2	HP310 x 132	Diesel	Cohesive	Friction
		2			Cohesive	Friction/End Bearing
		2	HP310 x 110		Cohesive	Friction
		2			Cohesive	Friction/End Bearing
23	16 MI. Creek Crossing Milton, ON	1	HP310 x 110	Diesel	Bedrock	End Bearing
24	Bridgepoint Court Bridge Aurora, ON	2	HP310 x 110	Diesel	Cohesive	Friction
25	CPR Bridge Crossing Major McKenzie Dr Vaughan, ON	2	HP310 x 110	Diesel	Layered	Friction
26	Gordie Howe Int. Bridge Windsor, ON	1	Pipe Pile	Diesel	Bedrock	End Bearing
27	Keith Bridge over E. Holland R. Newmarket, ON	6	HP310 x 110	Diesel	Cohesionless	End Bearing
28	Ott Rd. Bridge Fort Erie, ON	1	HP310 x 110	Diesel	Cohesionless	End Bearing
29	GO Station Pedestrian Bridge over Hwy. 401 Pickering, ON	2	HP310 x 79	Diesel	Cohesionless	End Bearing

Site #	Project	# of Tests	Pile Type	Hammer Type	Soil Strata	*Load-Transfer Mechanism
30	Weslie Creek Bridge St. Johns Sideroad York Region	1	HP310 x 110	Diesel	Cohesionless	End Bearing
31	H401 Expansion - CP Rail Bridge, WCC20	19	HP310 x 110	Diesel	Cohesionless	End Bearing
32	H401 Expansion- CN Rail Overhead Structures	6	HP310 x 110	Diesel	Cohesive	Friction
		2			Layered/Cohesionless	Friction/End Bearing
33	H401 Expansion - Credit River Bridge Structures	6	HP310 x 110	Diesel	Bedrock	End Bearing
34	CNR/CPR Structures - Northwest Metro Arterial	1	HP310 x 110 (HP12 x 74)	Diesel	Cohesionless	Friction
		1			Layered/Cohesionless	Friction/End Bearing
		1	Pipe Pile		Layered	Friction
		1			Cohesionless	Friction/End Bearing
		1	Precast Conc.		Cohesionless	End Bearing
		1	Timber		Layered/Cohesionless	Friction/End Bearing

* Load transfer mechanism are broadly interpreted based on subsurface setting.

5.6 Subsurface Strata Assessment

Each pile analyzed in the study was assessed for its load transfer mechanism and the subsurface strata in which the pile was installed. This was performed by superimposing the length of the pile (pile tip and final grade elevation extracted from pile driving summary/logs) on the soil profile at the location of the pile within the structure.

The load-transfer mechanism of each tested pile was analyzed and categorized into either 1) Skin Friction Soil Strata or 2) End Bearing Strata. For End Bearing piles, the soil strata could be classified as:

1. Cohesionless
2. Cohesive
3. Bedrock

For Skin-Friction Piles, the soil strata could be classified as:

1. Cohesionless
2. Cohesive
3. Layered (a mixture of cohesive and cohesionless soils deposited in layers)

The load transfer mechanism was evaluated primarily by the CAPWAP results, which estimates the distribution of forces between the shaft and tip of the pile. Where one CAPWAP analysis was performed for a series of piles in the same group, it was assumed that the force distribution would be similar for all piles provided that they were driven to about the same depth and soil type.

Where CAPWAP analyses were not performed, judgement was used to categorize the pile based on the soil's consistency/density at the pile tip and across the pile shaft. If the pile was driven to a hard/dense stratum with relatively weaker soils along the shaft, it was considered an end bearing pile. Conversely, if the soils around the pile tip were relatively weaker than those surrounding the shaft, the piles were considered as friction piles.

If the CAPWAP analysis indicated an approximately equal distribution of load transfer between the pile tip and shaft, the pile would be included in both categories. For the purpose of this assignment, a pile would be considered a combination of friction and end bearing if the larger proportion of load was under 60% of the total pile resistance (i.e., 59% end bearing and 41% shaft friction or vice versa). For cases where no CAPWAP analyses were performed, a pile would be considered in both categories if the soil surrounding the pile shaft and at the toe were the same density/consistency with high SPT blows counts (50+).

Additionally, piles could be categorized in two soil strata where the resistance distribution between the shaft and toe is equal but the soil along the shaft is different than the toe. For example, if the force distribution in the pile shows 59% resistance from the toe and 41% resistance from the shaft, with cohesive soils surrounding the shaft and cohesionless soils at the toe, the pile would be considered both cohesionless-end bearing and cohesive-friction.

5.7 Pile Driving Resistance

Because dynamic methods find it difficult to distinguish between the impacts of static and dynamic soil resistance at low blow counts (high set per blow), they have a tendency to overestimate static resistance.

For high blow count pile driving events, since not all of the resistance (especially at and around the toe) is fully active, dynamic test methods frequently result in lower bound nominal resistance estimates.

Taking into consideration the driving resistance of piles in the evaluation of PDA and Hiley tests may provide insight into which conditions these tests may be better suited for. For the purpose of this project, low blow events are assumed to be less than two blows per 25 mm and high blows are assumed to be greater than eight blows per 25 mm. Cases where the penetration resistance is between (and equal to) two and eight will be considered as "intermediate" driving resistance.

5.8 Statistical Analysis Procedure

Thirty-four sites were used in this study to compare PDA testing with the MTO Modified Hiley Formula. In addition, pile load tests were performed on 6 of the 34 sites identified in the project. The following sections present the statistical methodology used to evaluate the performance of the Hiley and PDA tests. The results were used to develop a strategy for the implementation of the PDA as a policy. The following analyses were made, of which a comprehensive discussion is made in the following sections:

1. Hiley and PDA tests compared to static pile load tests
2. Hiley and PDA tests compared to the ultimate resistance from FIDR
3. Hiley test compared to PDA test.

5.8.1 Hiley and PDA vs. Static Pile Load Tests

Static pile load tests were used as a benchmark for evaluating the accuracy of PDA and Hiley tests for estimating a driven pile's resistance. This analysis is based on a 1:1:1 comparison (i.e., one static load corresponds to one PDA test and one Hiley test); therefore, the analysis is considered a qualitative and quantitative analysis. It considers accuracy, consistency, and reproducibility in the analysis. A total of 18 piles were subjected to static pile load tests across the six sites. The statistical methods for this assessment are as follows:

1. Load Ratio:

$$Load\ ratio - Hiley\ to\ Static\ = \frac{Pile\ capacity,\ Hiley}{Pile\ capacity,\ Static}$$

$$Load\ ratio - PDA\ to\ Static\ = \frac{Pile\ capacity,\ PDA}{Pile\ capacity,\ Static}$$

2. Percentage of Error:

$$\%\ of\ Error - Hiley\ test = \frac{(Pile\ capacity,\ Static - Pile\ capacity,\ Hiley)}{Pile\ capacity,\ Static} \times 100$$

$$\%\ of\ Error - \text{PDA test} = \frac{(Pile\ capacity,\ Static - Pile\ capacity,\ PDA)}{Pile\ capacity,\ Static} \times 100$$

3. Linear regression analysis
4. Average, Min, Max,
5. Standard Deviation, σ:

σ is a measure of the amount of variation or dispersion of a set of values, which is calculated from the following equation:

$$\sigma = \sqrt{\frac{\sum(x_i - \bar{x})^2}{N}}$$

where:

x_i = each value from the dataset

$\bar{x}$ = mean value of the dataset

N = Number of samples

6. Coefficient of Variation, COV:

COV is a standardized measure of dispersion of a probability distribution or frequency distribution, which is calculated from the following equation:

$$COV\ (\%) = \frac{\sigma}{\bar{x}} \times 100$$

7. Coefficient of Determination, R^2:

R^2 is the proportion of the variation in the dependent variable that is predictable from the independent variable(s).

The results are presented in forms of:

1. Scatter Chart:
   a) To compare the results from PDA and Hiley tests with static tests
   b) To compare the results from percentage of error from PDA and Hiley tests with static pile capacities
2. Column Chart:
   a) To compare the load ratios, Hiley Capacity/Static Capacity vs. PDA Capacity/Static Capacity
   b) To provide range of variation of the results
3. Tables:
   a) Average, maximum, and minimum values of loads, load ratio, and percentage of error
   b) Standard Deviation
   c) Coefficient of Variation

5.8.2 Hiley and PDA vs. Ultimate Resistance from FIDR

A second series of analyses were performed to compare the Hiley and PDA test measurements with the ultimate resistance of piles provided in the FIDR's for each site. In total, 264 sets of tests containing both PDA and Hiley were used in the analysis. The analysis was conducted on piles that matched the testing event (EOID, BOR, or EOR) and testing period; therefore, the tests with a difference of more than two days between PDA and Hiley were eliminated.

The aim of this analysis is to show the variation of the data of both Hiley and PDA to the ultimate resistances provided in FIDR's, which are calculated mainly from static formulae informed by previous experience and related engineering judgement. Although static formulae are not necessarily a true measurement of a pile's resistance, they can be used as benchmark target for a qualitative analysis to measure the consistency and reproducibility of Hiley and PDA measurements. This analysis would also provide insight into which test more accurately achieves the target load reported in the FIDRs. The statistical methods for this assessment are as follows:

1. Load Ratio:

$$Load\ ratio - Hiley\ to\ FIDR\ = \frac{Pile\ capacity,\ Hiley}{Pile\ capacity,\ FIDR}$$

$$Load\ ratio - PDA\ to\ FIDR\ = \frac{Pile\ capacity,\ PDA}{Pile\ capacity,\ FIDR}$$

2. Percentage of Error:

$$\%\ of\ Error - Hiley\ test = \frac{(Pile\ capacity,\ FIDR - Pile\ capacity,\ Hiley)}{Pile\ capacity,\ FIDR} \times 100$$

$$\%\ of\ Error - \text{PDA test} = \frac{(Pile\ capacity,\ FIDR - Pile\ capacity,\ PDA)}{Pile\ capacity,\ FIDR} \times 100$$

3. Linear regression analysis
4. Average, Min, Max,
5. Standard Deviation, σ
6. Coefficient of Variation, COV

The results are presented in forms of:

1. Scatter Chart:
   a) To compare the results from PDA and Hiley capacities tests with the capacity reported in FIDR
   b) To compare the results from percentage of error from PDA and Hiley capacities tests with the capacity reported on FIDR
2. Column Chart:
   a) To compare the load ratios, Hiley Capacity/FIDR Capacity vs. PDA Capacity/FIDR Capacity
   b) To provide range of variation of the results
3. Tables:
   a) Average, maximum, and minimum values of loads, load ratio, and percentage of error
   b) Standard Deviation
   c) Coefficient of Variation

5.8.3 Hiley vs. PDA

A final evaluation was made directly comparing the Hiley and PDA test once an assessment of the validity of these two tests was made individually. Comparing Hiley/PDA with static pile load tests and target ultimate resistances will establish the better method to accurately and reliably predict the pile's actual capacity. The more reliable method will then serve as the benchmark in the comparison between the two test methods.

A total of 284 points were used in the analysis. The analysis was conducted on piles that matched the testing event (EOID, BOR, or EOR) and testing period; therefore, the tests with a difference of more than two days between PDA and Hiley were eliminated. The statistical methods for this assessment are as follows (the following formulae below assume PDA is the benchmark; however, the placement of PDA and Hiley inputs may reverse if Hiley is used as the benchmark test):

1. Load Ratio:

$$Load\ Ratio - Hiley\ to\ PDA\ = \frac{Pile\ capacity,\ Hiley}{Pile\ capacity,\ PDA}$$

2. Percentage of Error:

$$\%\ of\ Error = \frac{(Pile\ capacity,\ PDA - Pile\ capacity,\ Hiley)}{Pile\ capacity,\ PDA} \times 100$$

3. Linear regression analysis
4. Average, Min, Max,

5. Standard Deviation, σ
6. Coefficient of Variation, COV
7. Coefficient of Determination, R^2

The results are presented in forms of:

1. Scatter Chart:
   a) To compare the results from PDA and Hiley capacities tests with the capacity reported in FIDR
   b) To compare the results from percentage of error from PDA and Hiley capacities tests with the capacity reported on FIDR
2. Column Chart:
   a) To compare the load ratios, Hiley Capacity/FIDR Capacity vs. PDA Capacity/FIDR Capacity
   b) To provide range of variation of the results
3. Tables:
   a) Average, maximum, and minimum values of loads, load ratio, and percentage of error
   b) Standard Deviation
   c) Coefficient of Variation

6. Results and Analysis

6.1 Definition

The results of the statistical analysis are presented in forms of figures and tables. This section provides definitions for the figures' symbols. Figure 3 shows a sample figure from the comparison between pile load capacity, Hiley or PDA vs. pile capacity, static.

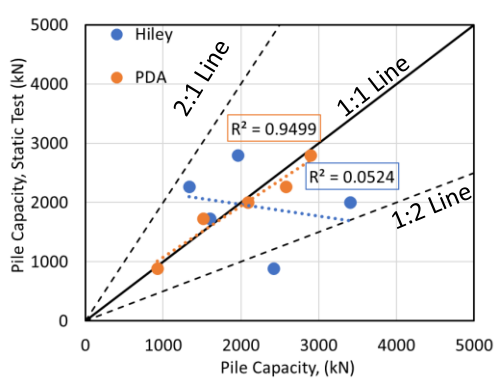


Figure 3 - Sample of Pile load capacity, Hiley or PDA vs. Pile capacity, Static

where:

1:1 Line = Line with slope 1

1:2 Line = Line that has a capacity equal to twice the capacity of 1:1 Line

2:1 Line = Line that has a capacity equal to half the capacity of 1:1 Line

Points aligned with the 1: 1 Line have perfect matching with the capacity obtained from static test (Y-axis)

Points aligned with the 1:2 Line have double the capacity obtained from static test (Y-axis)

Points aligned with the 2:1 Line have half the capacity obtained from static test (Y-axis)

Figure 4 shows the sample results of comparison of load ratio.

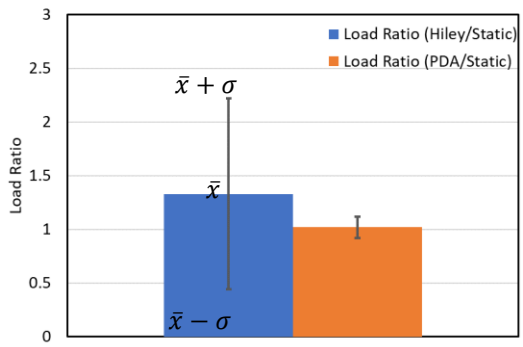


Figure 4 - Sample of Load ratio results

where:

$\bar{x}$ = Average value

$\bar{x} \pm \sigma$ = = Average value $\pm$ one standard deviation (68% of the data falls within this range)

Figure 4 shows the percentage of error (Hiley and PDA) vs. pile capacity from static test.

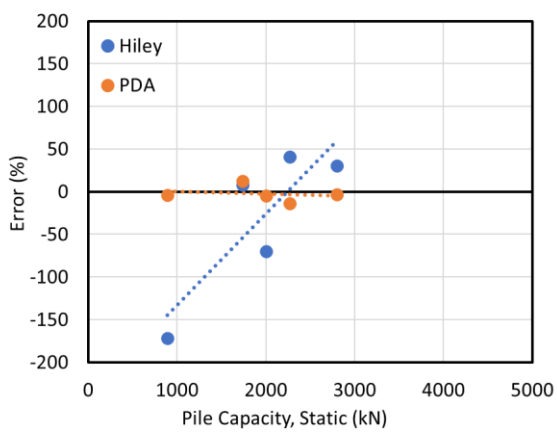


Figure 5 - Sample of percentage of error (Hiley and PDA) vs. pile capacity from static test

6.2 Hiley and PDA vs. Static Pile Load Tests

6.2.1 All Data

Figure 6 shows the comparison between the pile capacities of Hiley and PDA with respect to the static load test based on all data considered simultaneously. Figure 6 shows that the results of PDA tests were aligned with the 1:1 Line with a R^2 value of 0.63, while the results obtained from Hiley tests showed poor agreement with respect to the pile capacity results obtained from static load tests with a very low R^2 value (0.04). The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near both the 1:2 and 2:1 line. Table 2 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on all data.

Figure 7 and Table 3 shows that the results of PDA tests on average slightly underestimated the geotechnical capacity by 2%, with a COV of 20%, while Hiley tests overestimated the geotechnical capacity by 16%, with a COV of 50%. Table 3 shows a summary of the load ratio results based on all data.

Figure 8 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on all data. PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test. Table 2 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on all data.

Table 2 - Summary of the dataset of Hiley and PDA and comparison with the static pile load test based on all data

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to Static ULS Capacity	% of Error-PDA to Static ULS Capacity
Number of Points	18			
Average	2069	1899	-16	2
Max	3693	3576	41	42
Min	756	623	-172	-37
R^2	0.04	0.63	---	---

Table 3 - Summary of the load ratio results of Hiley and PDA with respect to the static pile load test capacity based on all data

	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)
No. of Points	18	
Average	1.16	0.98
Std Dev, σ	0.58	0.2
COV (%)	50	20
Max	2.72	1.37
Min	0.59	0.58

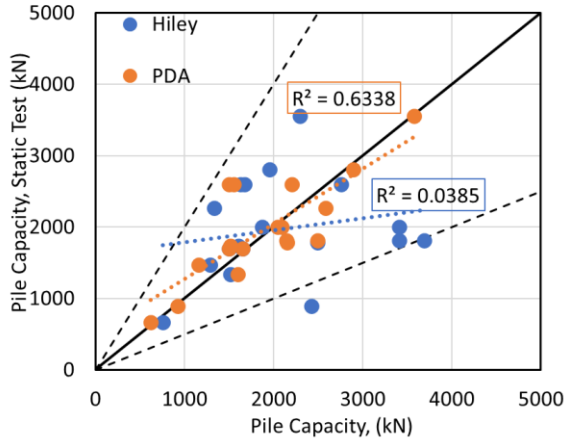


Figure 6 - Comparison between the pile capacities of Hiley and PDA with respect to the static load test based on all data

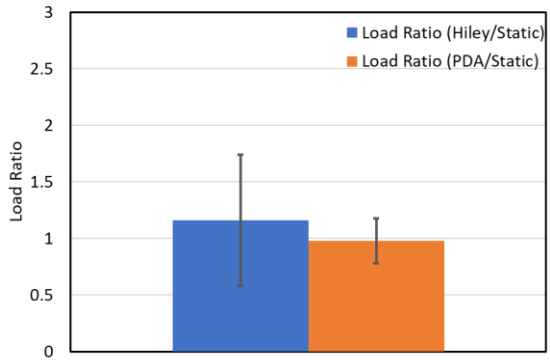


Figure 7 - Comparison between Hiley and PDA Load ratio with respect to the static load test based on all data

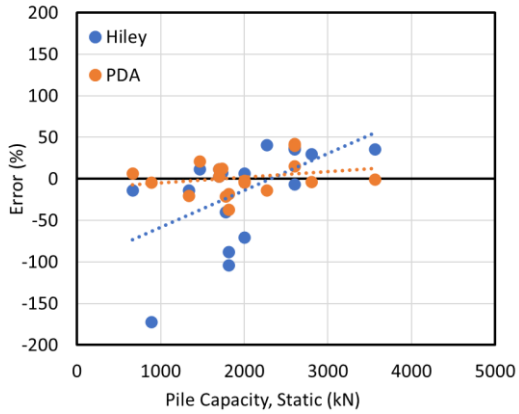


Figure 8 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on all data

6.2.2 Subsurface Condition and Load Transfer Mechanism

Figure 9 shows the comparison between the pile capacities of Hiley and PDA with respect to the static load test based on subsurface condition and load transfer mechanism. For end bearing piles seated in cohesionless soils, Figure 9a shows that the results of PDA tests were aligned with the 1:1 Line with R^2 of 0.58, while the results obtained from Hiley tests showed poor agreement with respect to the pile capacity results obtained from the static load test with a very low R^2 value (0.08). The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near both the 1:2 and 2:1 line. For friction piles driven into layered soils, Figure 9b shows that the results of PDA tests were aligned well with the 1:1 Line with a R^2 of 0.95, while the results obtained from Hiley tests showed poor agreement with respect to the pile capacity results obtained from the static load test with a very low R^2 value (0.05). The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near both the 1:2 and 2:1 line. For friction piles driven into cohesionless soils (Figure 9c), no conclusive discussion can be made based on two points. More data is required to have a clear conclusion. However, based on the two data points, the Hiley test data points landed closer to the 1:1 line compared to points from the PDA tests. Table 4 shows a summary of the dataset of Hiley and PDA compared to the static pile load tests based on subsurface conditions and load transfer mechanism.

Figure 10 and Table 5 shows the comparison between Hiley and PDA load ratio with respect to the static load tests based on subsurface condition and load transfer mechanisms. For end bearing piles rested on cohesionless soils, Figure 10a and Table 5 shows that the results of PDA tests on average slightly underestimated the geotechnical capacity by 2%, with a COV of 22%, while Hiley tests overestimated the geotechnical capacity by 7%, with a COV of 41%. For friction piles driven into layered soils, Figure 10b and Table 5 shows that the results of PDA tests on average slightly underestimated the geotechnical capacity by 2%, with a COV of 10%, while Hiley tests overestimated the geotechnical capacity by 33%, with a COV of 67%. For friction piles driven into cohesionless soils (Figure 10c), no conclusive discussion can be made based on two points. More data is required to have a clear conclusion. However, based on the limited data points, both tests on average are close to unity. Table 5 shows a summary of the load ratio results based on subsurface conditions and load transfer mechanism.

Figure 11 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load tests based on subsurface condition and load transfer mechanism. For end bearing piles seated into cohesionless soils, and friction piles installed into layered soils (Figure 11 and Figure 11b), PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test. For friction piles driven into cohesionless soils (Figure 11c), no conclusive discussion can be made based on two points. More data is required to have a clear conclusion. Table 4 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on subsurface conditions and load transfer mechanism.

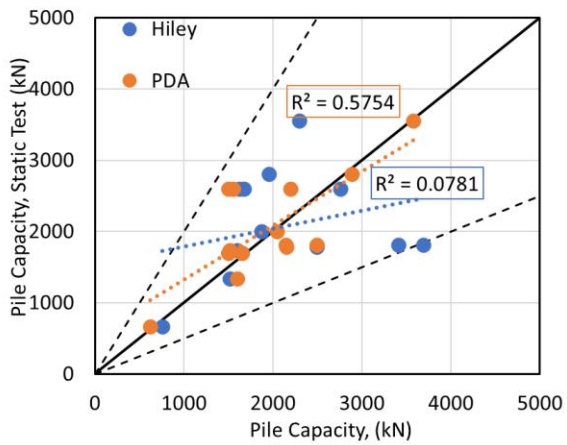
For end bearing piles in cohesive soil, no data available based on static load test. Nonetheless, the analysis has been conducted using the FIDR ULS resistance as the reference, as outlined in Section 6.3.2, and in particular, Figure 39c, Figure 40c, and Figure 41c.

Table 4 - Summary of the dataset of Hiley and PDA and comparison with the static pile load test based on subsurface conditions and load transfer mechanism

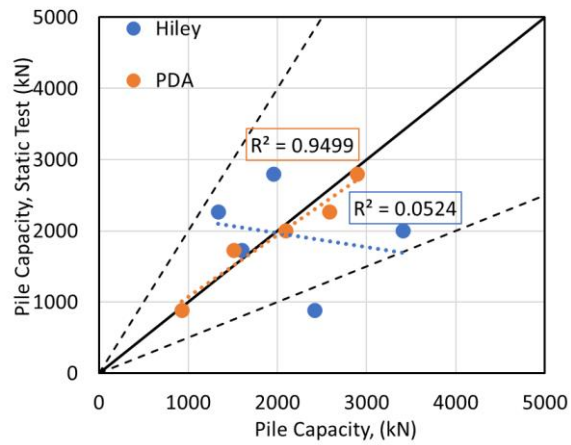
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to Static ULS Capacity	% of Error-PDA to Static ULS Capacity
Parameter	End Bearing - Cohesionless			
Number of Points	14			
Average	2057	1960	-7	2
Max	3693	3576	38	42
Min	756	623	-103	-37
R^2	0.08	0.58	---	---
Parameter	Friction - Layered			
Number of Points	5			
Average	2144	2000	-33	-2
Max	3407	2891	41	13
Min	1334	925	-172	-14
R^2	0.05	0.95	---	---
Parameter	Friction - Cohesionless			
Number of Points	2			
Average	1401	1379	-1	1
Max	1512	1601	12	21
Min	1290	1157	-13	-20
R^2	1	1	---	---

Table 5 - Summary of the load ratio results of Hiley and PDA with respect to the static pile load test capacity based on subsurface conditions and load transfer mechanism

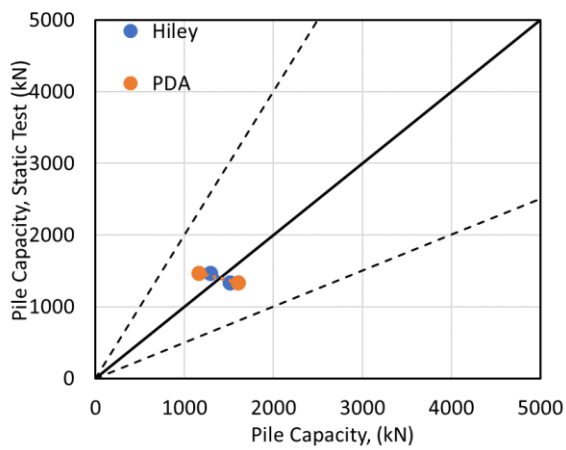
	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)
Parameter	End Bearing - Cohesionless		Friction - Layered		Friction - Cohesionless	
No. of Points	14		5		2	
Average	1.07	0.98	1.33	1.02	1.01	1
Std Dev, σ	0.44	0.22	0.89	0.1	0.18	0.29
COV (%)	41	22	67	10	18	29
Max	2.03	1.37	2.72	1.14	1.13	1.2
Min	0.63	0.58	0.59	0.87	0.88	0.79



a) End Bearing Piles – Cohesionless Soil

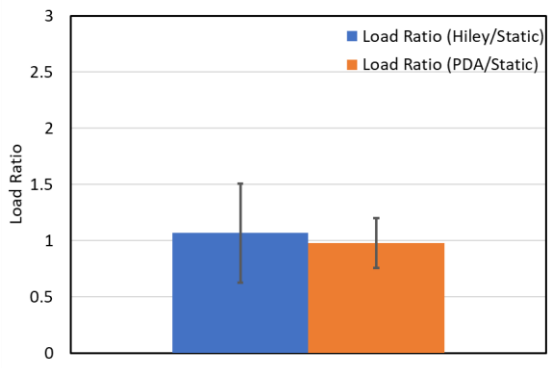


b) Friction Piles – Layered Soil Strata

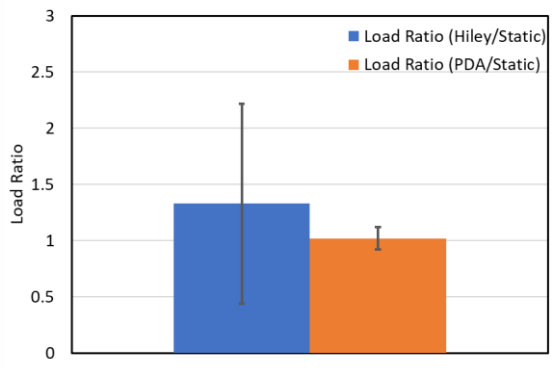


c) Friction Piles – Cohesionless Soil

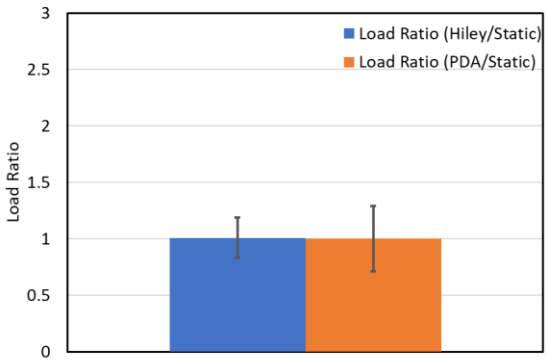
Figure 9 - Comparison between the pile capacities of Hiley and PDA with respect to the static load test based on subsurface conditions and load transfer mechanism



a) End Bearing Piles – Cohesionless Soil

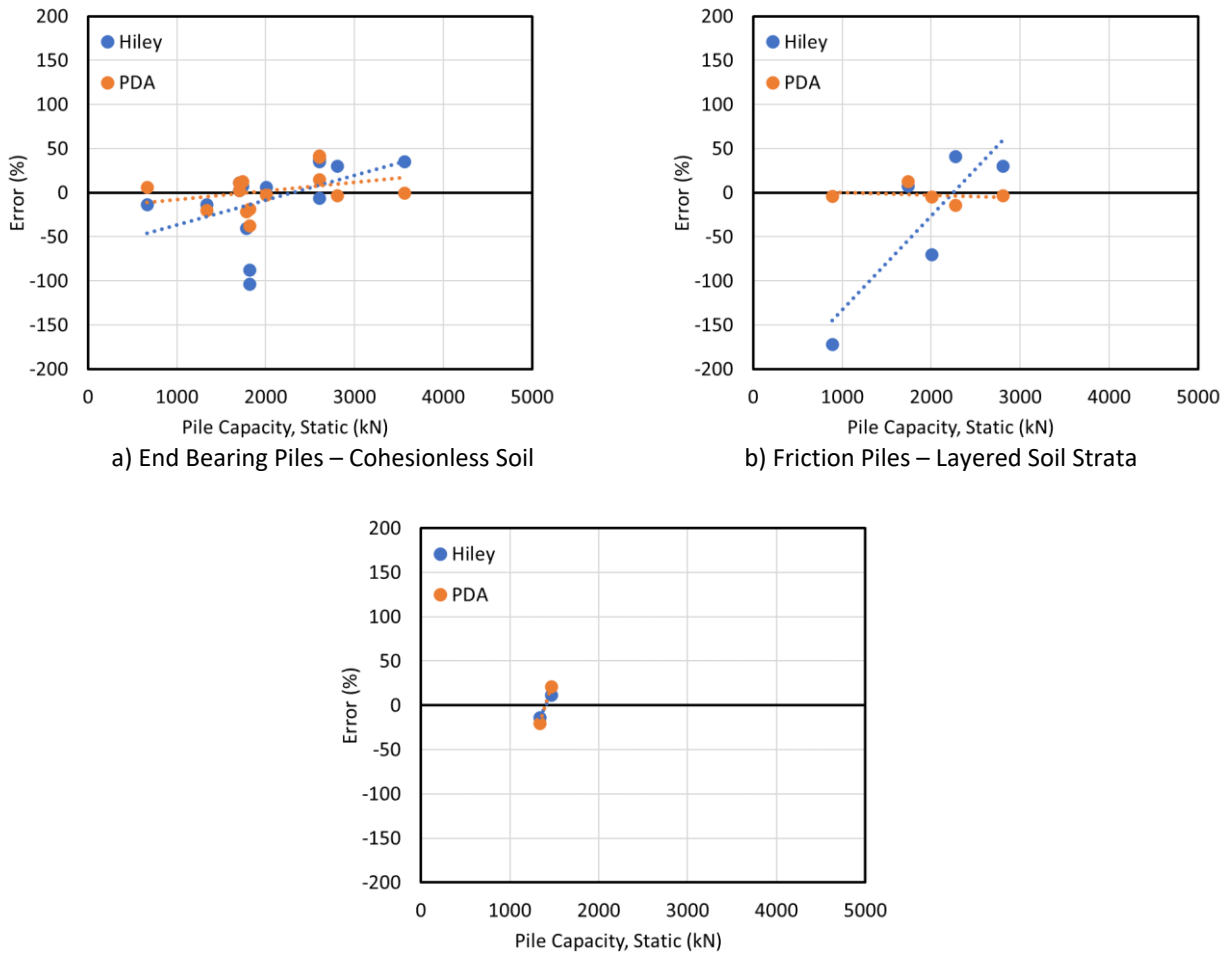


b) Friction Piles – Layered Soil Strata



c) Friction Piles – Cohesionless Soil

Figure 10 - Comparison between Hiley and PDA Load ratio with respect to the static load test based on subsurface condition and load transfer mechanism



a) End Bearing Piles – Cohesionless Soil

b) Friction Piles – Layered Soil Strata

c) Friction Piles – Cohesionless Soil

Figure 11 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on subsurface condition and load transfer mechanism

6.2.3 Pile Type

Figure 12 shows the comparison between the pile capacities of Hiley and PDA with respect to the static load tests based on pile type. For H-Piles, Figure 12a shows that the results of PDA tests were aligned with the 1:1 Line with a R^2 of 0.49, while the results obtained from Hiley tests showed poor agreement with respect to the pile capacity results obtained from the static load test with an extremely low R^2 value (3E-05). The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near both the 1:2 and 2:1 line. For pipe piles, Figure 12b shows that the results of PDA tests are aligned well with the 1:1 Line with a R^2 of 0.92, while the results obtained from Hiley tests showed a higher level of scatter. For precast concrete piles, Figure 12c shows that the results of PDA tests are aligned with the 1:1 Line with a R^2 of 0.31, while the results obtained from Hiley tests showed poor agreement and tended to overestimate the capacity with respect to the pile capacity results obtained from the static load test although it has a high R^2 value . For timber piles (Figure 12 d), the results of PDA tests showed more accurate results compared to Hiley tests with respect to static load tests; however, more data is required to have a clearer conclusion. Table 6 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the pile Type.

Figure 13 and Table 7 shows the comparison between Hiley and PDA load ratio with respect to the static load tests based on the pile Type. For H-Pile, Figure 13a and Table 7 shows that the results of PDA tests on average underestimated the geotechnical capacity by 7%, with a COV of 26%, while Hiley tests slightly overestimated the geotechnical capacity by 3%, with a COV of 50%. For pipe piles, Figure 13b and Table 7 shows that the results of PDA tests on average underestimated the geotechnical capacity by 12%, with COV of 8%, while Hiley tests slightly underestimated the geotechnical capacity by 12%, with a COV of 31%. For precast piles, Figure 13c and Table 7 shows that the results of PDA tests on average slightly overestimated the geotechnical capacity by 4%, with a COV of 16%, while Hiley tests considerably overestimated the geotechnical capacity by 34%, with a COV of 29%. For timber piles (Figure 13 d), the results of PDA tests showed more accurate results compared to Hiley tests with respect to static load test; however, more data is required to furnish a clearer conclusion. The lower COV for PDA indicates better repeatability and reliability in achieving the actual pile capacity compared to Hiley tests.

Figure 14 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on pile type. For all piles (Figure 14a, Figure 14b, Figure 14c, and Figure 14d), PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load tests. Table 6 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the pile type.

Table 6 - Summary of the dataset of Hiley and PDA and comparison with the static pile load test based on pile type

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to Static ULS Capacity	% of Error-PDA to Static ULS Capacity
Parameter	H-Piles			
Number of Points	10			
Average	2185	2066	-3	7
Max	3693	3576	38	42
Min	1290	1157	-103	-37
R^2	0	0.49	---	---
Parameter	Pipe Piles			
Number of Points	3			
Average	1572	2076	11	-12
Max	1868	2580	41	-2
Min	1334	1601	-13	-20
R^2	0.01	0.92	---	---
Parameter	Precast Concrete Piles			
Number of Points	3			
Average	2500	1919	-34	-4
Max	3407	2153	8	13
Min	1601	1512	-70	-21
R^2	0.88	0.31	---	---
Parameter	Timber Piles			
Number of Points	2			
Average	1588	774	-93	1
Max	2420	925	-13	7
Min	756	623	-172	-4
R^2	1	1	---	---

Table 7 - Summary of the load ratio results of Hiley and PDA with respect to the static pile load test capacity based on pile type

	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)
Parameter	H-Piles		Pipe Piles	
No. of Points	10		3	
Average	1.03	0.93	0.88	1.12
Std Dev, σ	0.51	0.24	0.27	0.09
COV (%)	50	26	31	8
Max	2.03	1.37	1.13	1.2
Min	0.63	0.58	0.59	1.02
Parameter	Precast Concrete Piles		Timber Piles	
No. of Points	3			
Average	1.34	1.04	1.93	0.99
Std Dev, σ	0.39	0.17	1.12	0.08
COV (%)	29	16	58	8
Max	1.7	1.21	2.72	1.04
Min	0.92	0.87	1.13	0.93

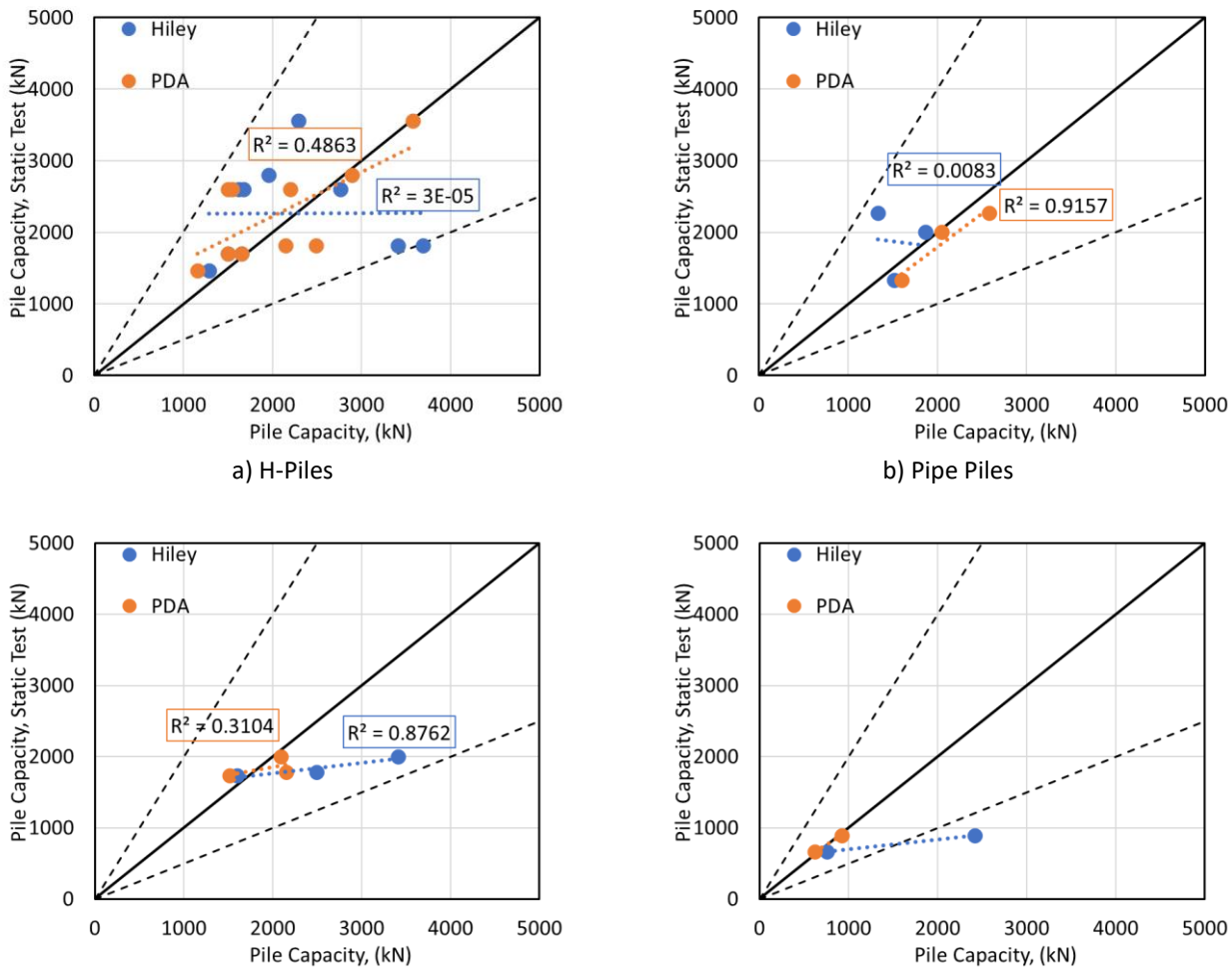
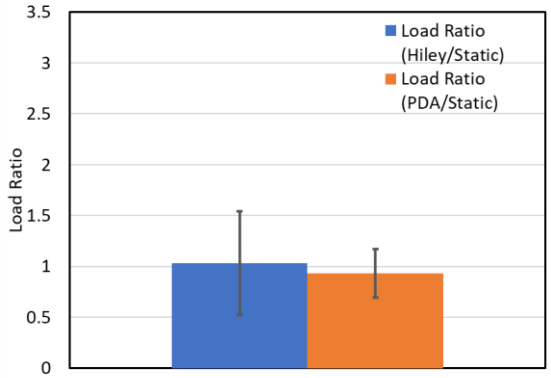
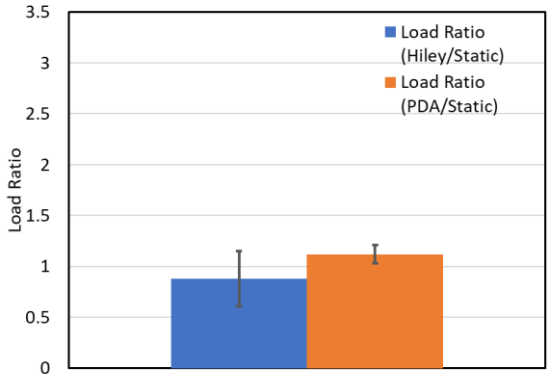


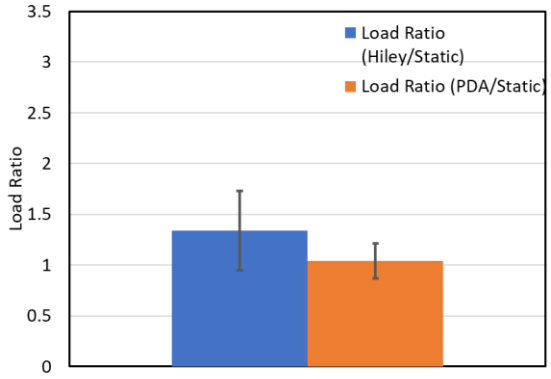
Figure 12 - Comparison between the pile capacities of Hiley and PDA with respect to the static load test based on pile type



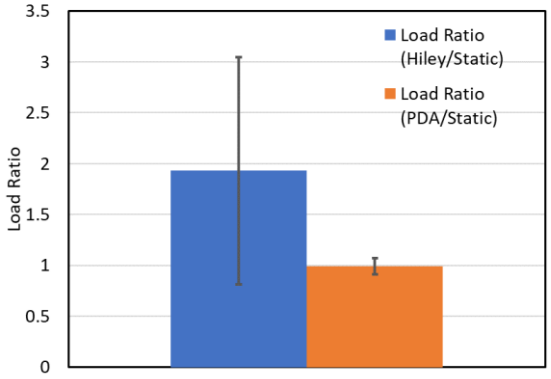
a) H-Piles



b) Pile Piles



c) Precast Concrete Piles



d) Timber Piles

Figure 13 - Comparison between Hiley and PDA Load ratio with respect to the static load test based on pile type

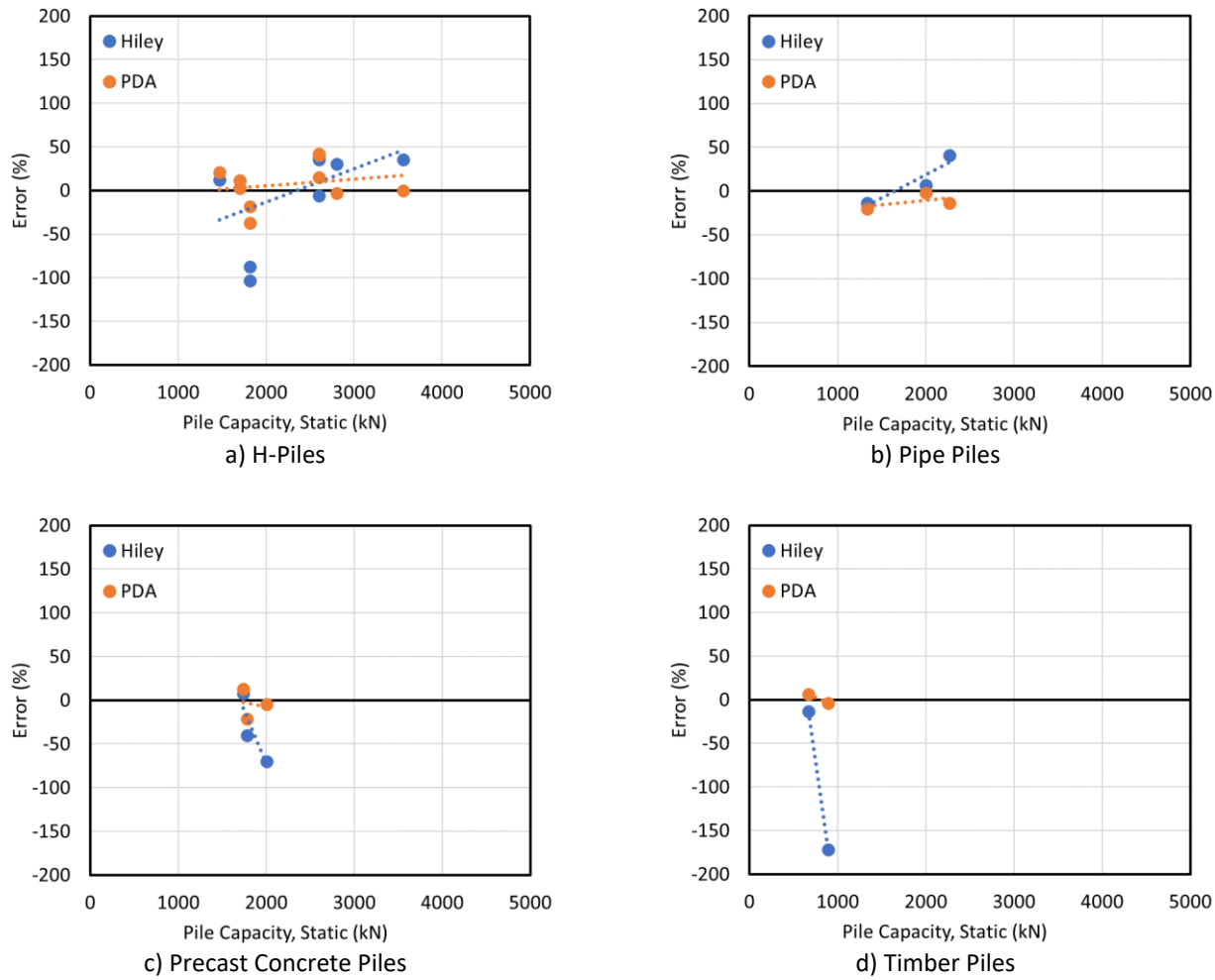


Figure 14 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on pile type

6.2.4 Pile Embedment Length

Figure 15 shows the comparison between the pile capacities of Hiley and PDA with respect to the static load test based on pile embedment lengths. For piles with embedment lengths equal to or less than 24 m, Figure 15a shows that the results of PDA tests were aligned with the 1:1 Line with a R^2 value of 0.87, while the results obtained from Hiley tests showed a higher level of scatter with a lower R^2 value (0.35). For piles with an embedment length between 24 m to 60 m, Figure 15b shows that the results of PDA tests were aligned with the 1:1 Line with a R^2 value of 0.25, while the results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near both the 1:2 and 2:1 line. Table 8 shows a summary of the dataset of Hiley and PDA compared to the static pile load tests based on pile embedment lengths.

Figure 16 and Table 9 shows the comparison between Hiley and PDA load ratio with respect to the static load test based on pile embedment length. For piles with embedment lengths equal to or less than 24 m, Figure 16a and Table 9 shows that the results of PDA tests on average slightly underestimated the geotechnical capacity by 5% with a COV of 14%, while Hiley tests overestimated the geotechnical capacity by 27% with a COV of 47%. For piles with an embedment length between 24 m to 60 m, Figure 16b and Table 9 shows that the results of PDA tests on average slightly overestimated the geotechnical capacity by 2%

a with COV of 26%, while Hiley tests overestimated the geotechnical capacity by 5% with a COV of 54%. Table 9 shows a summary of the load ratio results based on pile embedment length.

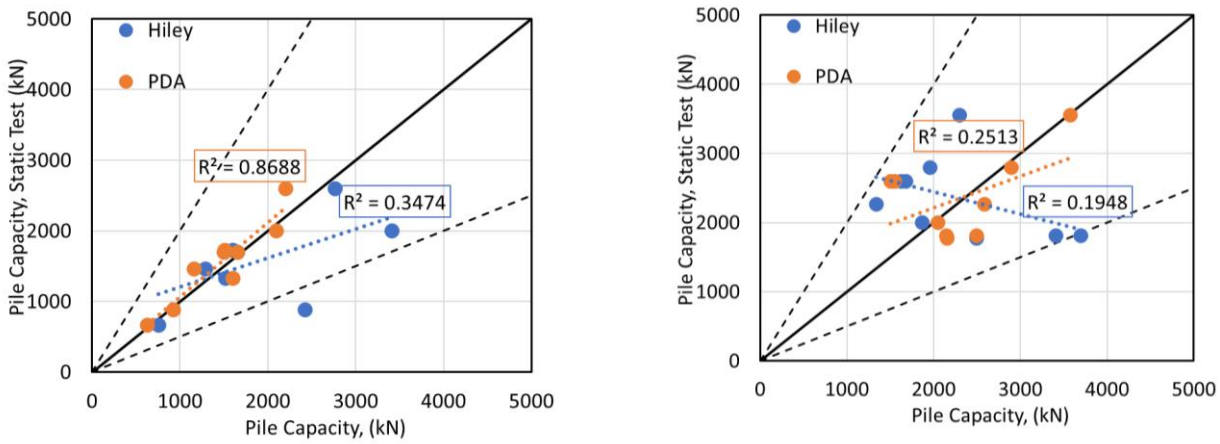
Figure 17 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on pile's embedment lengths. As shown in Figure 17a and Figure 17b, PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test. Table 8 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on pile embedment length.

Table 8 - Summary of the dataset of Hiley and PDA and comparison with the static pile load test based on pile embedment length

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to Static ULS Capacity	% of Error-PDA to Static ULS Capacity
Parameter	Embedment Length, L ≤ 24 m			
Number of Points	9			
Average	1877	1473	-27	5
Max	3407	2200	12	21
Min	756	623	-172	-20
R^2	0.35	0.87	---	---
Parameter	Embedment Length 24 < L ≤ 60 m			
Number of Points	9			
Average	2261	2326	-5	-1
Max	3693	3576	41	42
Min	1334	1500	-103	-37
R^2	0.19	0.25	---	---

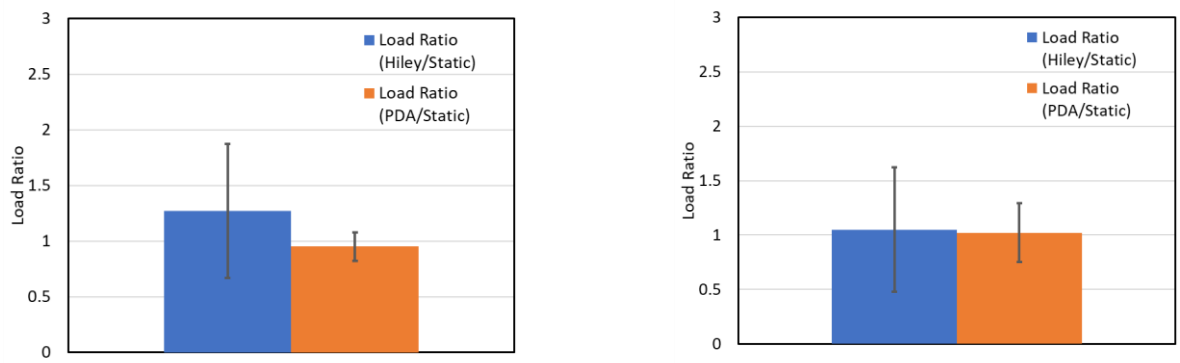
Table 9 - Summary of the load ratio results of Hiley and PDA with respect to the static pile load test capacity based on pile embedment length

	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)
Parameter	Embedment Length, L ≤ 24 m		Embedment Length 24 < L ≤ 60 m	
No. of Points	9		9	
Average	1.27	0.95	1.05	1.02
Std Dev, σ	0.6	0.13	0.57	0.27
COV (%)	47	14	54	26
Max	2.72	1.2	2.03	1.37
Min	0.88	0.79	0.59	0.58



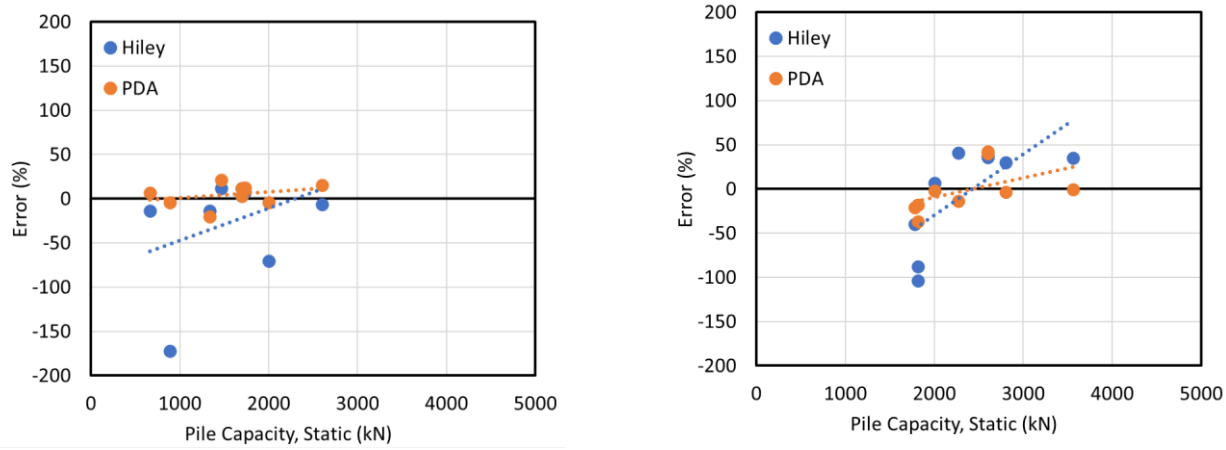
a) Pile Length, L ≤ 24 m b) Pile Length 24 < L ≤ 60 m

Figure 15 - Comparison between the pile capacities of Hiley and PDA with respect to the static load test based on pile embedment length



a) Pile Length, L ≤ 24 m b) Pile Length 24 < L ≤ 60 m

Figure 16 - Comparison between Hiley and PDA Load ratio with respect to the static load test based on pile embedment length



a) Pile Length, L ≤ 24 m b) Pile Length 24 < L ≤ 60 m

Figure 17 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on the pile embedment length

6.2.5 Pile Splice

Figure 18 shows the comparison between the pile capacities of Hiley and PDA with respect to the static load test based on pile splice. For spliced piles, Figure 18a shows that the results of PDA tests were aligned with the 1:1 Line with a R^2 value of 0.44, while the results obtained from Hiley tests showed a higher level of scatter with a lower R^2 value (0.35). The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near both the 1:2 and 2:1 line. For piles which have not been spliced, Figure 18b shows that the results of PDA tests were aligned well with 1:1 Line with a R^2 value of 0.98, while the results obtained from Hiley tests showed a higher level of scatter. Table 10 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on pile splice.

Figure 19 and Table 11 shows the comparison between Hiley and PDA load ratio with respect to the static load test based on pile splice. For spliced piles, Figure 19a and Table 11 shows that the results of PDA tests accurately predict the geotechnical capacity with a COV of 24%, while Hiley tests overestimated the geotechnical capacity by 8% with a COV of 47%. For piles which have not been spliced, Figure 19 and Table 11 shows that the results of PDA tests on average underestimated the geotechnical capacity by 7% with a COV of 9%, while Hiley tests overestimated the geotechnical capacity by 35% with a COV of 57%. Table 11 shows a summary of the load ratio results based on pile splice.

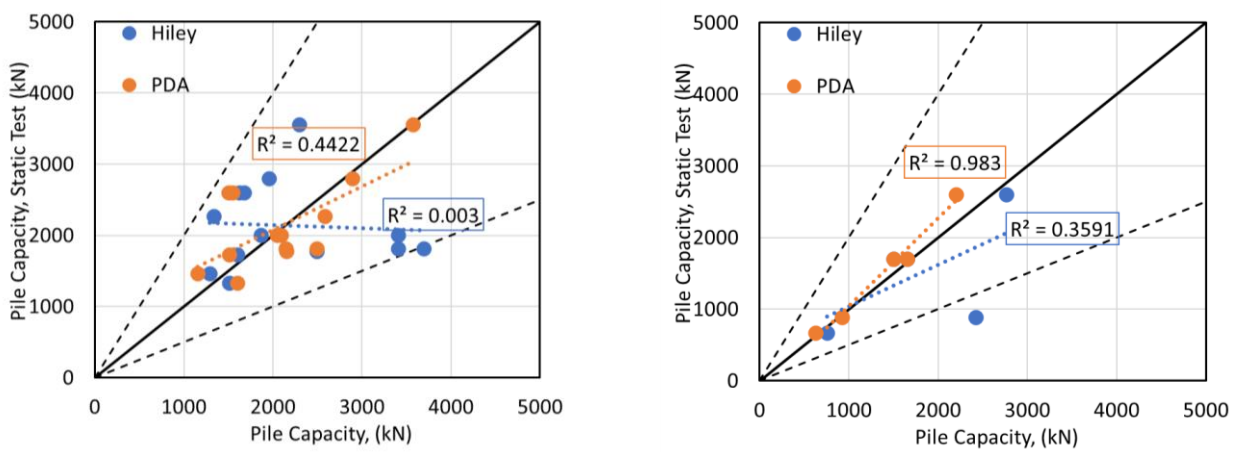
Figure 20 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on pile splice. As shown in Figure 20a and Figure 20b, PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test. Table 10 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on pile splice.

Table 10 - Summary of the dataset of Hiley and PDA and comparison with the static pile load test based on pile splice

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to Static ULS Capacity	% of Error-PDA to Static ULS Capacity
Parameter	With Splice			
Number of Points	13			
Average	2166	2099	-8	0
Max	3693	3576	41	42
Min	1290	1157	-103	-37
R^2	0	0.44	---	---
Parameter	Without Splice			
Number of Points	5			
Average	1817	1380	-35	7
Max	2760	2200	12	15
Min	756	623	-172	-4
R^2	0.36	0.98	---	---

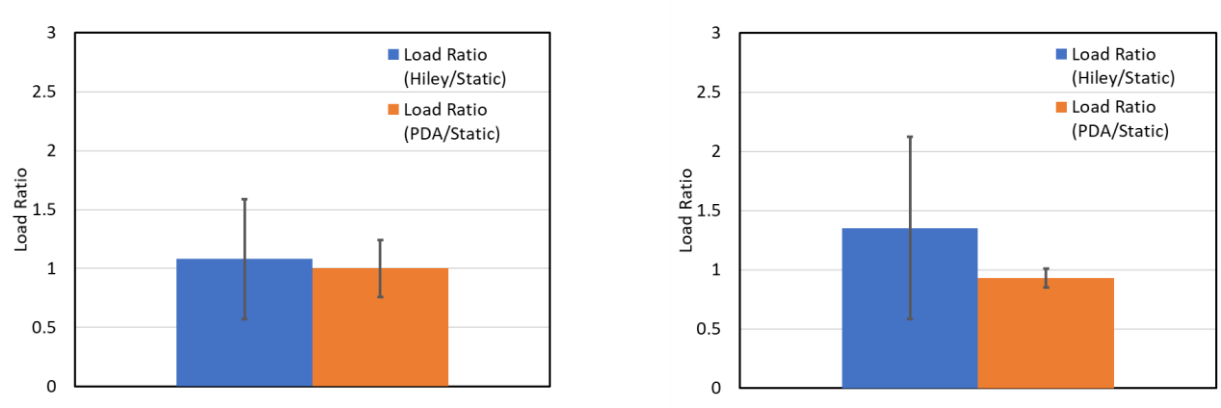
Table 11 - Summary of the load ratio results of Hiley and PDA with respect to the static pile load test capacity based on pile splice

	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)
Parameter	With Splice		Without Splice	
No. of Points	13		5	
Average	1.08	1	1.35	0.93
Std Dev, σ	0.51	0.24	0.77	0.08
COV (%)	47	24	57	9
Max	2.03	1.37	2.72	1.04
Min	0.59	0.58	0.88	0.85



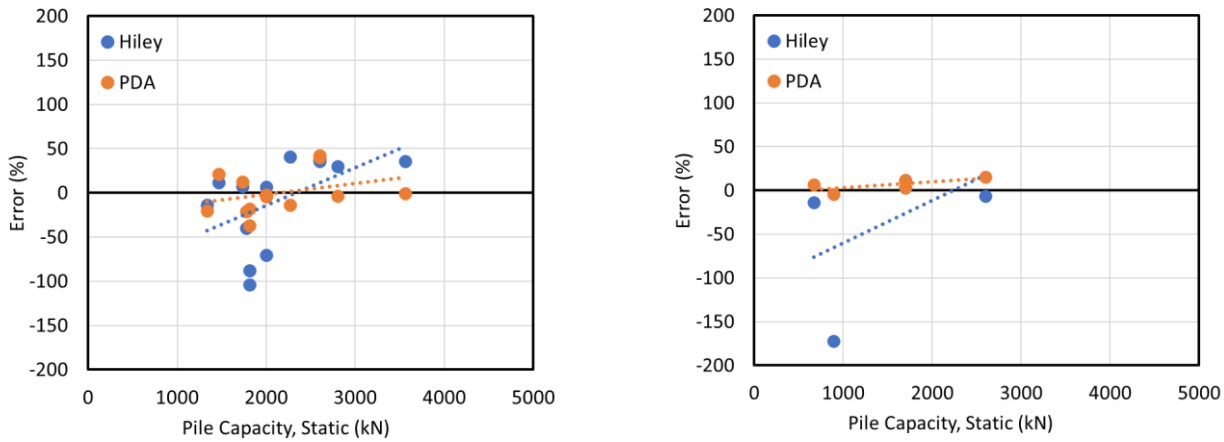
a) With Splice b) Without Splice

Figure 18 - Comparison between the pile capacities of Hiley and PDA with respect to the static load test based on pile splice



a) With Splice b) Without Splice

Figure 19 - Comparison between Hiley and PDA Load ratio with respect to the static load test based on pile splice



a) With Splice b) Without Splice

Figure 20 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on pile splice

6.2.6 Pile Driving Event

Figure 21 shows the comparison between the pile capacities of Hiley and PDA with respect to the static load test based on pile driving event. For piles tested at the end of initial driving (EOID), Figure 21a shows that the results of PDA tests were aligned with the 1:1 Line with few points near the 2:1 line and a R^2 value of 0.68, while the results obtained from Hiley tests showed a higher level of scatter with a low R^2 value (0.09). For piles tested at beginning of restrike (BOR), Figure 21b shows that the results of PDA tests provided less scattered data compared with Hiley tests with respect to static load test; both provided a low R^2. For piles tested at end of restrike (EOR) (Figure 21c) shows that the results of PDA tests were aligned with the 1:1 Line with an R^2 value of 0.97, while the results obtained from Hiley tests showed a higher level of scatter with a low R^2 value (0.04).Table 12 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the pile driving event.

Figure 22 and Table 13 show the comparison between Hiley and PDA load ratio with respect to the static load test based on the driving event. For piles tested at the end of initial driving (EOID), Figure 22a and Table 13 shows that the results of PDA tests on average slightly underestimated the geotechnical capacity by 4% with a COV of 21%, while Hiley tests overestimated the geotechnical capacity by 17% with a COV of 56%. For piles tested at the beginning of restrike (BOR), Figure 22b and Table 13 shows that the results of PDA tests on average slightly underestimated the geotechnical capacity by 4% with a COV of 33%, while Hiley tests overestimated the geotechnical capacity by 13% with a COV of 55%. For piles tested at end of restrike (EOR), Figure 22**c** and Table 13 shows that the results of PDA tests on average slightly overestimated the geotechnical capacity by 7% with a COV of 8%, while Hiley tests overestimated the geotechnical capacity by 17% with a COV of 40%. Table 13 shows a summary of the load ratio results based on the driving event.

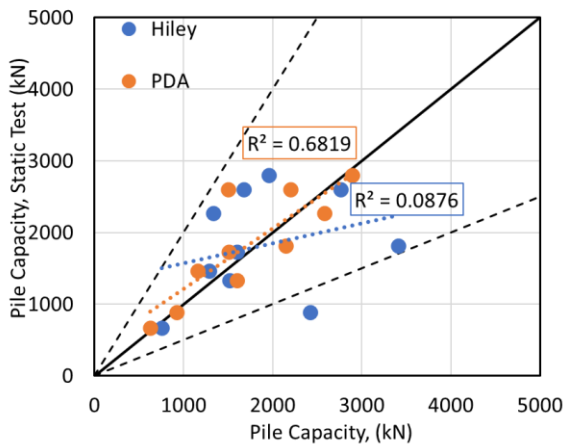
Figure 23 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on the driving event. At all driving events (Figure 23a, Figure 23b and Figure 23c), PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test. Table 12 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the driving events.

Table 12 - Summary of the dataset of Hiley and PDA and comparison with the static pile load test based on driving events

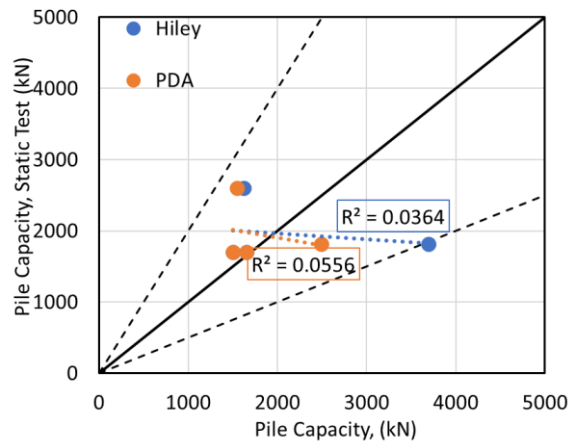
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to Static ULS Capacity	% of Error-PDA to Static ULS Capacity
Parameter	End of Initial Drive (EOID)			
Number of Points	10			
Average	1871	1713	-17	4
Max	3407	2891	41	42
Min	756	623	-172	-20
R^2	0.09	0.68	---	---
Parameter	Beginning of Restrike (BOR)			
Number of Points	4			
Average	2117	1798	-13	4
Max	3693	2490	38	40
Min	1500	1500	-103	-37
R^2	0.04	0.06	---	---
Parameter	End of Restrike (EOR)			
Number of Points	4			
Average	2515	2467	-17	-7
Max	3407	3576	36	-1
Min	1868	2046	-70	-21
R^2	0.04	0.97	---	---

Table 13 - Summary of the load ratio results of Hiley and PDA with respect to the static pile load test capacity based on driving events

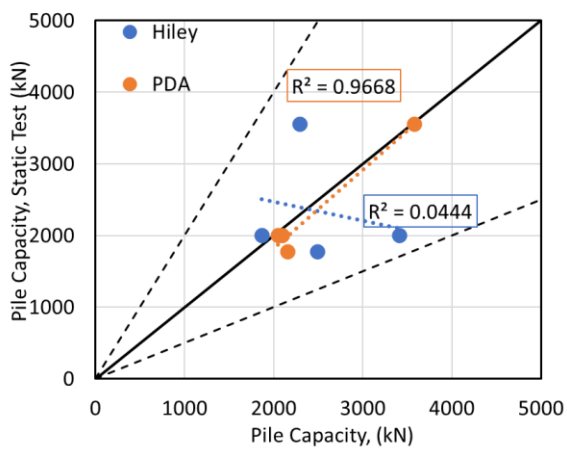
	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)
Parameter	End of Initial Drive (EOID)		Beginning of Restrike (BOR)		End of Restrike (EOR)	
No. of Points	10		4		4	
Average	1.17	0.96	1.13	0.96	1.17	1.07
Std Dev, σ	0.66	0.2	0.62	0.32	0.47	0.09
COV (%)	56	21	55	33	40	8
Max	2.72	1.2	2.03	1.37	1.7	1.21
Min	0.59	0.58	0.63	0.6	0.65	1.01



a) End of Initial Drive (EOID)

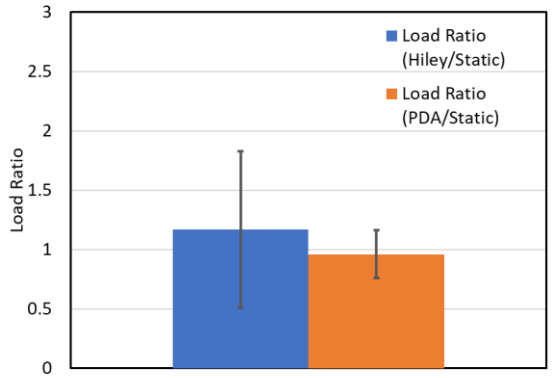


b) Beginning of Restrike (BOR)

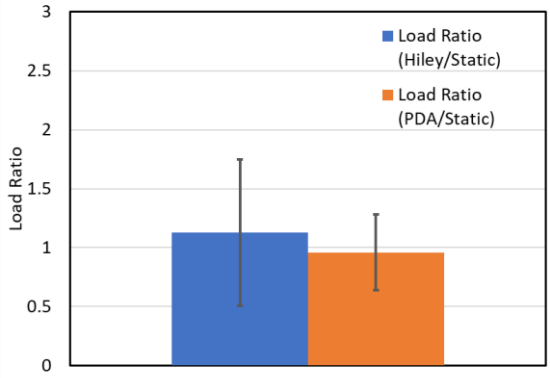


c) End of Restrike (EOR)

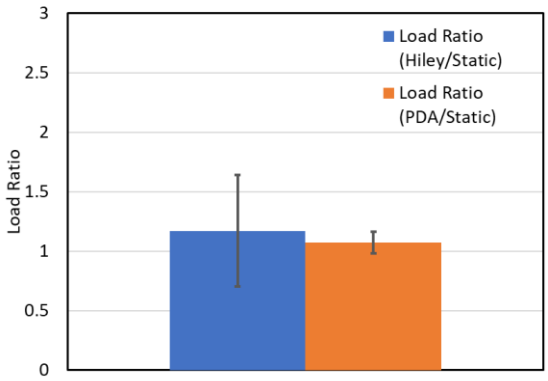
Figure 21 - Comparison between the pile capacities of Hiley and PDA with respect to the static load test based on driving events



a) End of Initial Drive (EOID)

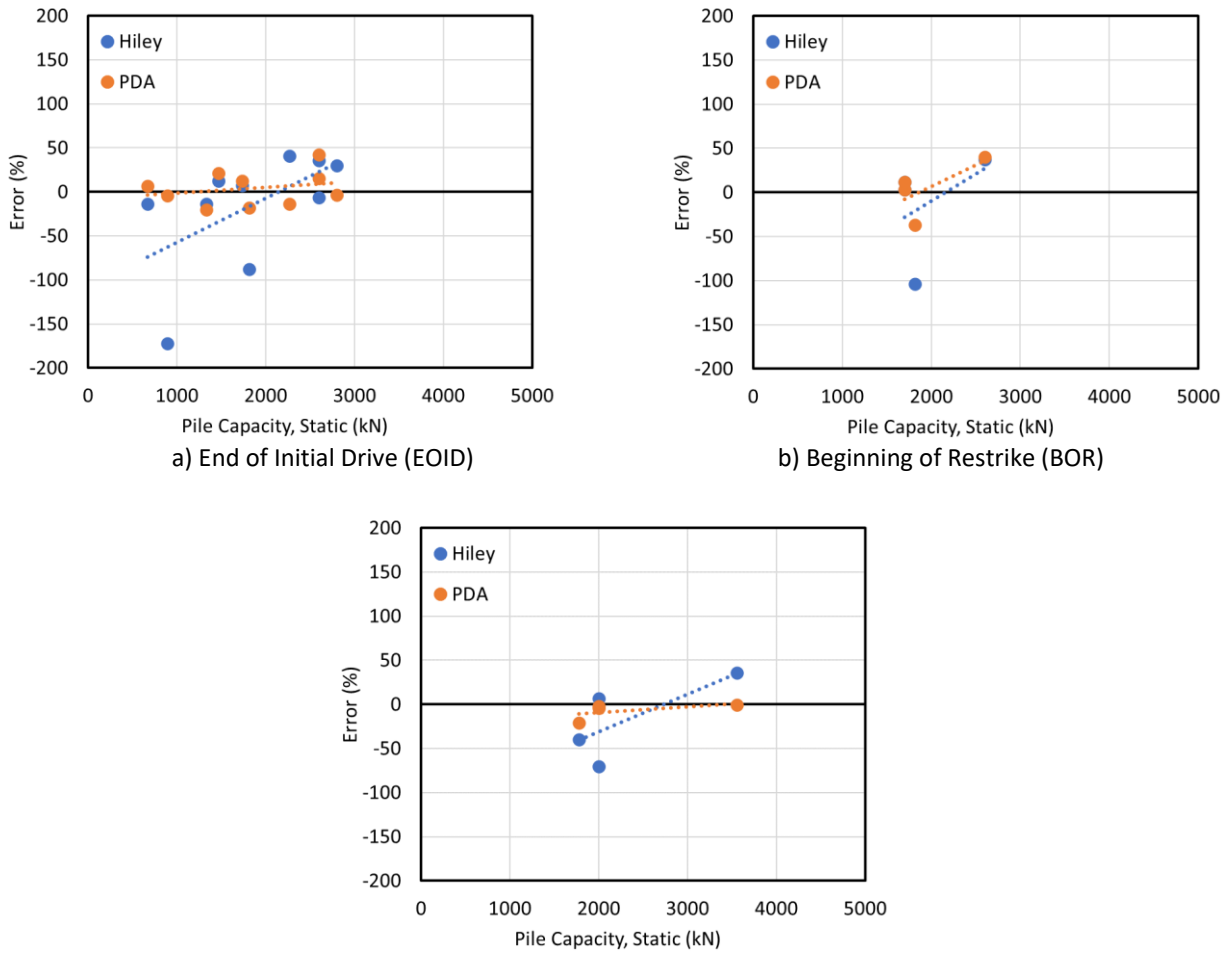


b) Beginning of Restrike (BOR)



c) End of Restrike (EOR)

Figure 22 - Comparison between Hiley and PDA Load ratio with respect to the static load test based on driving event



a) End of Initial Drive (EOID)

b) Beginning of Restrike (BOR)

c) End of Restrike (EOR)

Figure 23 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on driving event

6.2.7 Hammer System

Figure 24 shows the comparison between the pile capacities of Hiley and PDA with respect to the static load test based on the hammer system. For piles driven with diesel hammers, Figure 24a shows that the results of PDA tests were aligned with the 1:1 Line with a R^2 value of 0.86, while the results obtained from Hiley tests showed a higher level of scatter with a low R^2 value (0.08). The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near both the 1:2 and 2:1 line. For piles driven with hydraulic hammers, Figure 24b shows that both PDA and Hiley underestimated the geotechnical capacity; however, no conclusive conclusion can be made based on two points. More data is required for further analysis. Table 14 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the hammer system.

Figure 25 and Table 15 show the comparison between Hiley and PDA load ratio with respect to the static load test based on the hammer system. For piles driven with diesel hammers, Figure 25a and Table 15 shows that the results of PDA tests on average slightly overestimated the geotechnical capacity by 3% with a COV of 16%, while Hiley tests overestimated the geotechnical capacity by 22% with a COV of 48%. For piles driven with hydraulic hammers, Figure 25b and Table 15 shows that both PDA and

Hiley tests underestimated the geotechnical capacity, however, no conclusive conclusion can be made based on two points; more data is required for further analysis. Table 15 shows a summary of the load ratio results based on the hammer system.

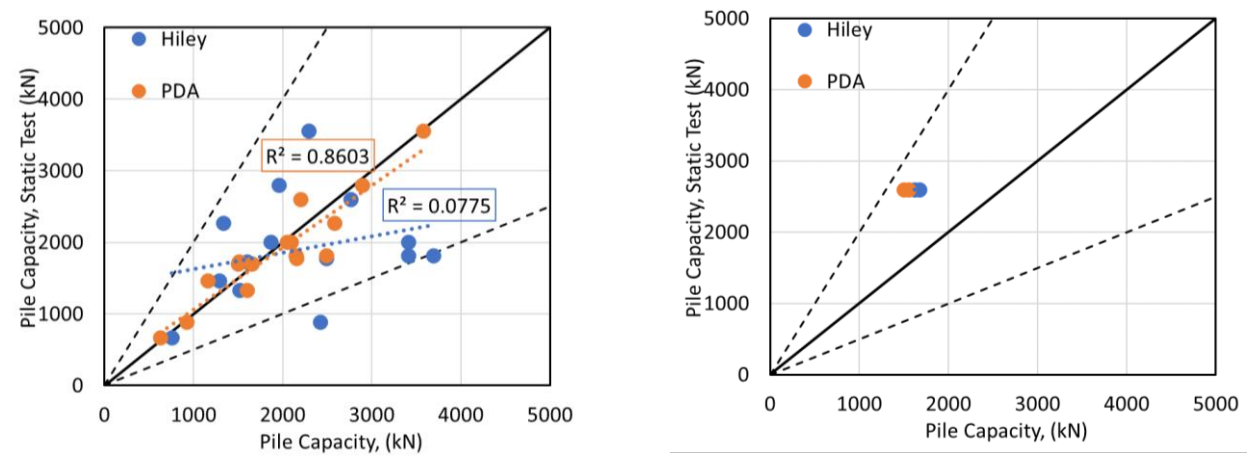
Figure 26 and Table 14 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on the hammer system. As shown in Figure 26, PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test for piles driven with diesel hammers. For piles driven with hydraulic hammers, no conclusive conclusion can be made based on two points. More data is required for further analysis. Table 14 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the hammer system.

Table 14 - Summary of the dataset of Hiley and PDA and comparison with the static pile load test based on the hammer systems

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to Static ULS Capacity	% of Error-PDA to Static ULS Capacity
Parameter	Diesel Hammers			
Number of Points	16			
Average	2121	1946	-22	-3
Max	3693	3576	41	21
Min	756	623	-172	-37
R^2	0.08	0.86	---	---
Parameter	Hydraulic Hammers			
Number of Points	2			
Average	1650	1525	37	41
Max	1675	1550	38	42
Min	1625	1500	36	40
R^2	N/A	N/A	---	---

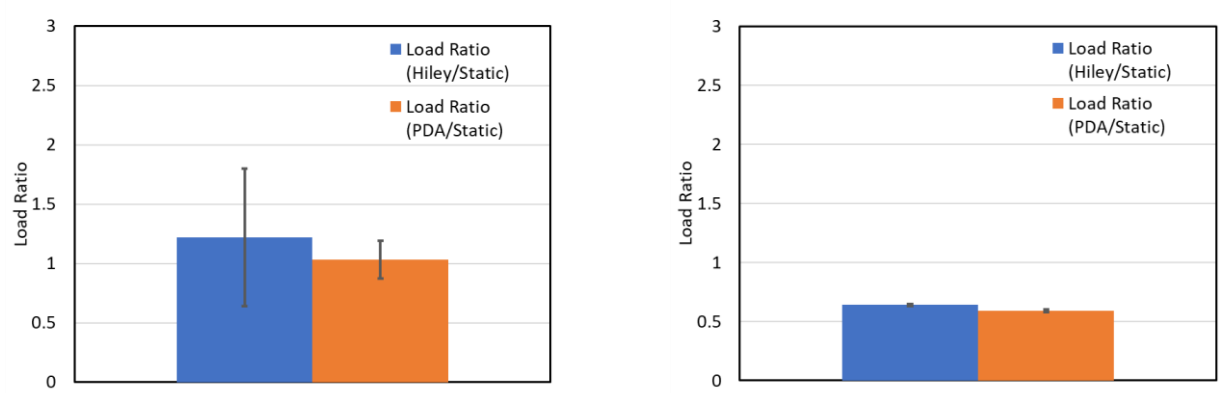
Table 15 - Summary of the load ratio results of Hiley and PDA with respect to the static pile load test capacity based on the hammer systems

	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)
Parameter	Diesel Hammers		Hydraulic Hammers	
No. of Points	16		2	
Average	1.22	1.03	0.64	0.59
Std Dev, σ	0.58	0.16	0.01	0.01
COV (%)	48	16	2	2
Max	2.72	1.37	0.64	0.6
Min	0.59	0.79	0.63	0.58



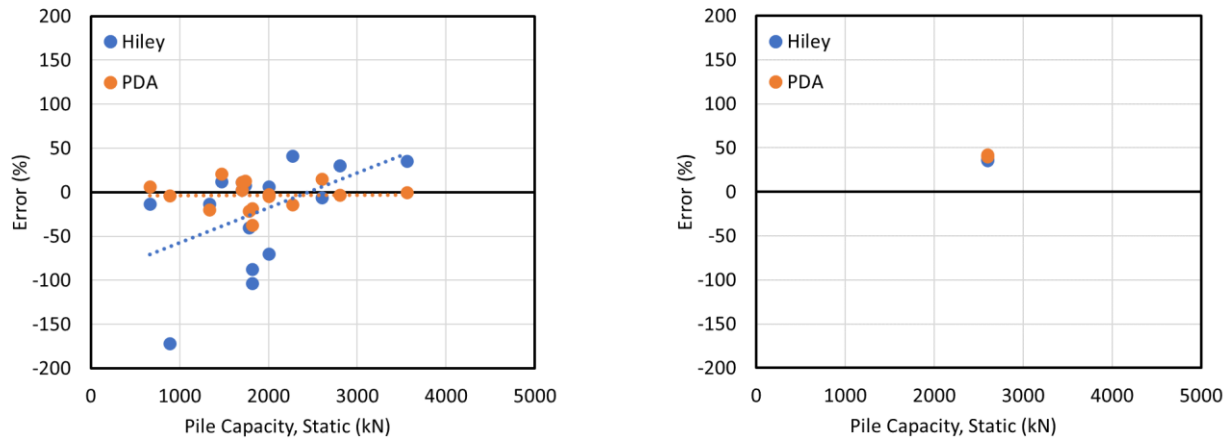
a) Diesel Hammers b) Hydraulic Hammers

Figure 24 - Comparison between the pile capacities of Hiley and PDA with respect to the static load test based on the hammer systems



a) Diesel Hammers b) Hydraulic Hammers

Figure 25 - Comparison between Hiley and PDA Load ratio with respect to the static load test based on the hammer systems



a) Diesel Hammers b) Hydraulic Hammers

Figure 26 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the hammer systems

6.2.8 Pile Cushion

Figure 27 shows the comparison between the pile capacities of Hiley and PDA with respect to the static load test based the use of a pile cushion. For piles driven with a cushion, Figure 27a shows that the results of PDA tests were aligned with the 1:1 Line with a R^2 value of 0.90, while the results obtained from Hiley tests showed a higher level of scatter with a low R^2 value of 0.22. For piles driven without a pile cushion, Figure 27b shows that the results of PDA tests were aligned well with the 1:1 Line with a R^2 of 0.5, while the results obtained from Hiley tests showed a higher level of scatter with points landing near both the 1:2 and 2:1 line. Table 16 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the use of a pile cushion.

Figure 28 and Table 17 shows the comparison between Hiley and PDA load ratio with respect to the static load test based on the use of pile cushion. For piles driven with a pile cushion, Figure 28a and Table 17 shows that the results of PDA tests on average slightly overestimated the geotechnical capacity by 3% with a COV of 15%, while Hiley tests overestimated the geotechnical capacity by 6% with a COV of 35%. For piles driven without a pile cushion, Figure 28b show and Table 17 that the results of PDA tests on average slightly underestimated the geotechnical capacity by 5% with a COV of 25%, while Hiley tests overestimated the geotechnical capacity by 24% with a COV of 58%. Table 17 shows a summary of the load ratio results based on whether the use of a pile cushion was employed.

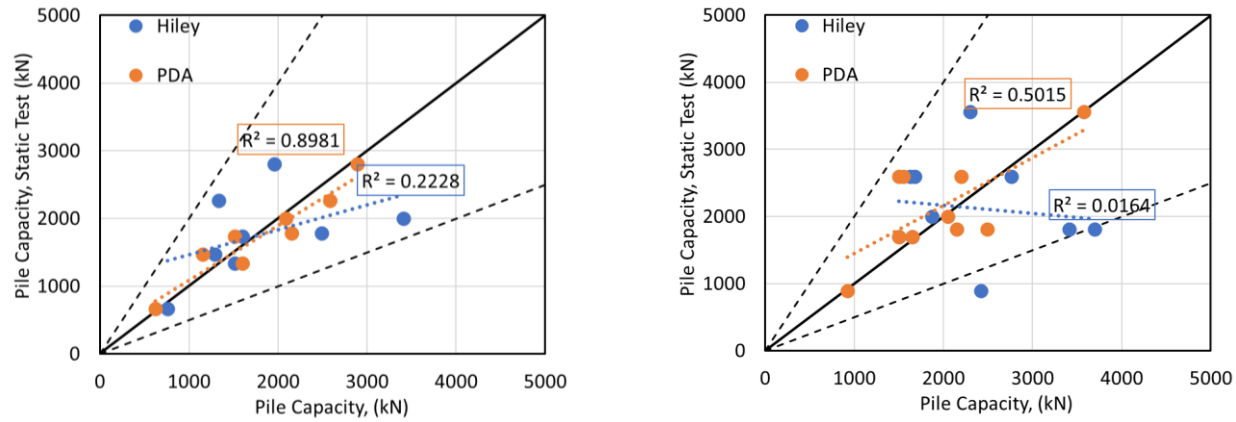
Figure 29 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on the use of a pile cushion. As shown in Figure 29a and Figure 32b, PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test. Table 18 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the using pile cushion.

Table 16 - Summary of the dataset of Hiley and PDA and comparison with the static pile load test based on the use of pile cushion

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to Static ULS Capacity	% of Error-PDA to Static ULS Capacity
Parameter	Pile Driven with Cushion			
Number of Points	8			
Average	1794	1826	-6	-3
Max	3407	2891	41	21
Min	756	623	-70	-21
R^2	0.22	0.9	---	---
Parameter	Pile Driven without Cushion			
Number of Points	10			
Average	2289	1958	-24	5
Max	3693	3576	38	42
Min	1500	925	-172	-37
R^2	0.02	0.5	---	---

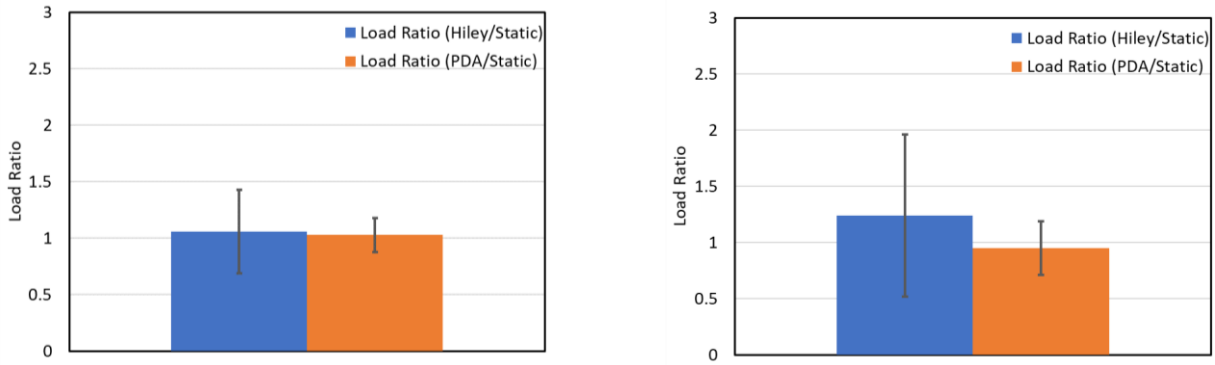
Table 17 - Summary of the load ratio results of Hiley and PDA with respect to the static pile load test capacity based on the use of pile cushion

	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)
Parameter	Piles Driven with Cushion		Piles Driven without Cushion	
No. of Points	8		10	
Average	1.06	1.03	1.24	0.95
Std Dev, σ	0.37	0.15	0.72	0.24
COV (%)	35	15	58	25
Max	1.7	1.21	2.72	1.37
Min	0.59	0.79	0.63	0.58



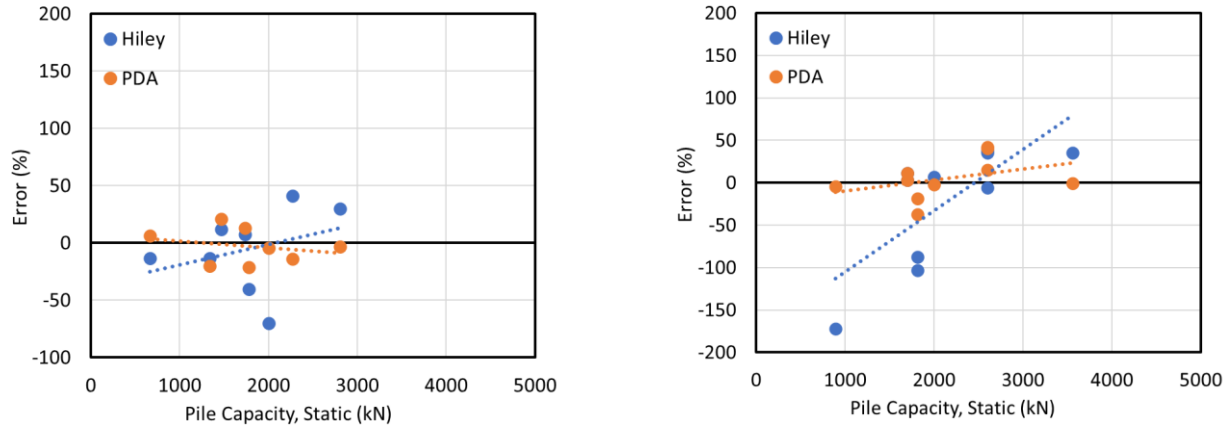
a) With Cushion b) Without Cushion

Figure 27 - Comparison between the pile capacities of Hiley and PDA with respect to the static load test based on the use of cushion



a) With Cushion b) Without Cushion

Figure 28 - Comparison between Hiley and PDA Load ratio with respect to the static load test based on the use of cushion



a) With Cushion b) Without Cushion

Figure 29 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the use of cushion

6.2.9 Pile Driving Shoe/Bearing Point

Figure 30 the comparison between the pile capacities of Hiley and PDA with respect to the static load test based on the use of a driving shoe/bearing point. For piles driven with a driving shoe/bearing point, Figure 30a shows that the results of PDA tests were aligned with 1:1 Line with some values near the 2:1 line with an R^2 value of 0.87, while the results obtained from Hiley tests showed a higher level of scatter with a very low R^2 value (0). The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near the 1:2 line and 2:1 line. For piles driven without driving shoe/bearing point, Figure 30b shows that the results of PDA tests were aligned well with 1:1 Line with an R^2 value of 0.99, while the results obtained from Hiley tests showed a higher level of scatter with points landing near the 1:2 line and 2:1 line. Table 18 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the use of a driving shoe/bearing point.

Figure 31 and Table 19 show the comparison between Hiley and PDA load ratio with respect to the static load test based on the use of a driving shoe/bearing point. For piles driven with a driving shoe/bearing point, Figure 31a and Table 19 show that the results of PDA tests on average slightly underestimated the geotechnical capacity by 1% with a COV of 24%, while Hiley tests overestimated the geotechnical capacity by 11% a with COV of 44%. For piles driven without driving a shoe/bearing point, Figure 31b and Table 19 show that the results of PDA tests on average slightly underestimated the geotechnical capacity by 3% with a COV of 7%, while Hiley tests overestimated the geotechnical capacity by 27% with a COV of 65%. Table 19 shows a summary of the load ratio results based on the use of a driving shoe/bearing point.

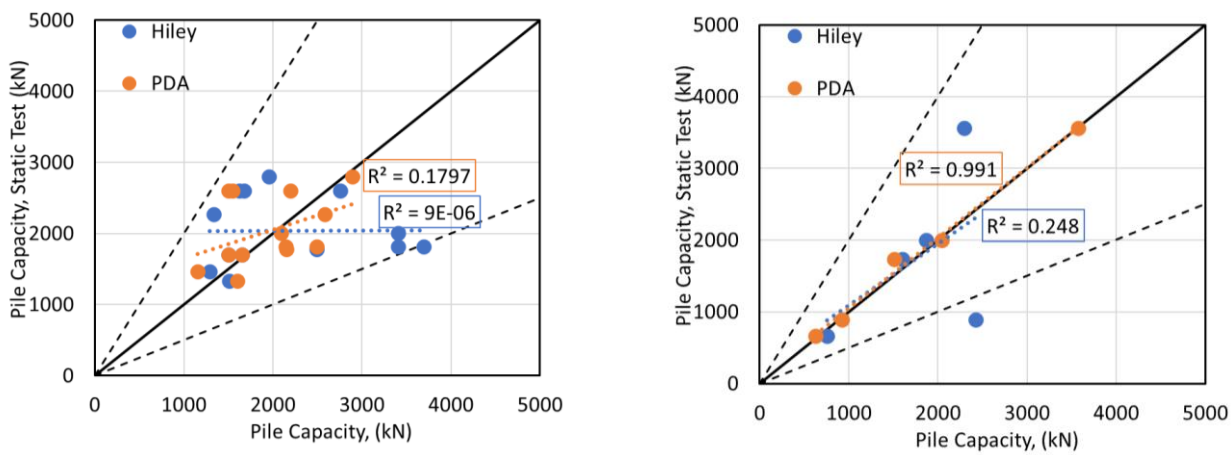
Figure 32 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test. As shown in Figure 32a and Figure 32b, PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test. Table 18 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the use of a driving shoe/bearing point.

Table 18 - Summary of the dataset of Hiley and PDA and comparison with the static pile load test based on the use of a driving shoe/bearing point

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to Static ULS Capacity	% of Error-PDA to Static ULS Capacity
Parameter	With Pile Shoe/Bearing Point			
Number of Points	13			
Average	2177	1962	-12	1
Max	3693	2891	41	42
Min	1290	1157	-103	-37
R^2	0	0.18	---	---
Parameter	Without Pile Shoe/Bearing Point			
Number of Points	5			
Average	1788	1737	-27	3
Max	2420	3576	36	13
Min	756	623	-172	-4
R^2	0.25	0.99	---	---

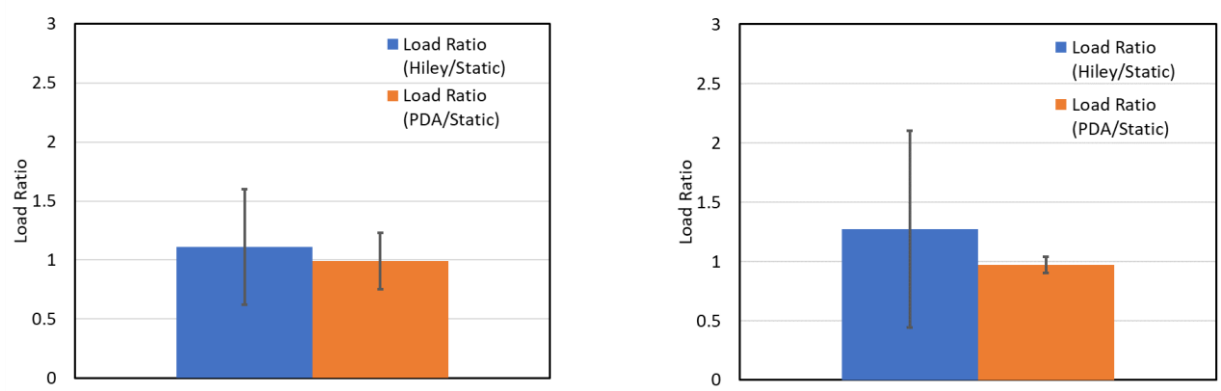
Table 19 - Summary of the load ratio results of Hiley and PDA with respect to the static pile load test capacity based on the use of a driving shoe/bearing point

	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)
Parameter	With Pile Shoe/Bearing Point		Without Pile Shoe/Bearing Point	
No. of Points	13		5	
Average	1.11	0.99	1.27	0.97
Std Dev, σ	0.49	0.24	0.83	0.07
COV (%)	44	24	65	7
Max	2.03	1.37	2.72	1.04
Min	0.59	0.58	0.65	0.87



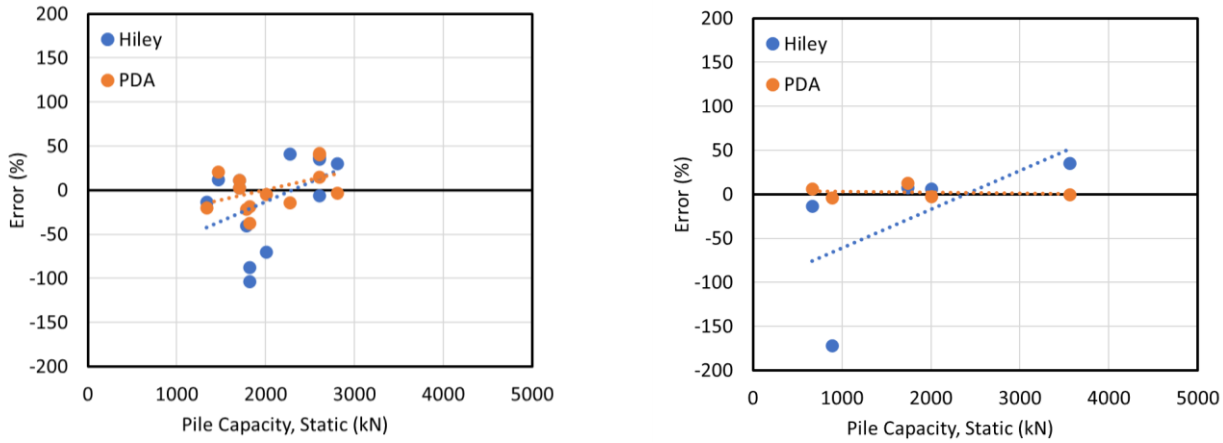
a) With Pile Shoe/Bearing Point b) Without Pile Shoe/Bearing Point

Figure 30 - Comparison between the pile capacities of Hiley and PDA with respect to the static load test based on the use of a driving show/bearing point



a) With Pile Shoe/Bearing Point b) Without Pile Shoe/Bearing Point

Figure 31 - Comparison between Hiley and PDA Load ratio with respect to the static load test based on the use of a driving show/bearing point



a) With Pile Shoe/Bearing Point b) Without Pile Shoe/Bearing Point

Figure 32 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based the use of a driving shoe/bearing point

6.2.10 Hammer Rated Energy

Figure 33 shows the comparison between the pile capacities of Hiley and PDA with respect to the static load test based on the hammer rated energy (E). For piles driven hammer rated energy between 30 kJ and 90 kJ, Figure 33a shows that the results of PDA tests were aligned with 1:1 Line with an R^2 value of 0.70, while the results obtained from Hiley tests showed a higher level of scatter with a low R^2 value (0.1). The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near the 1:2 line and 2:1 line. For piles driven hammer rated energy more than 90 kJ, Figure 33b shows that the results of PDA tests were close to 1:1 Line with an R^2 value of 0.88, while the results obtained from Hiley tests showed a higher level of scatter with points landing near the 1:2 line. Table 20 shows a summary of the dataset of Hiley and PDA compared to the static pile load tests based on the hammer rated energy.

Figure 34 and Table 21 show the comparison between Hiley and PDA load ratio with respect to the static load test based on the hammer rated energy. For piles driven hammer rated energy between 30 kJ and 90 kJ, Figure 34a and Table 21show that the results of PDA tests on average slightly underestimated the geotechnical capacity by 5% with a COV of 21%, while Hiley tests overestimated the geotechnical capacity by 8% with a COV of 53%. For piles driven hammer rated energy more than 90 kJ, Figure 34b and Table 21 show that that the results of PDA tests on average slightly overestimated the geotechnical capacity by 10% with a COV of 20%, while Hiley tests overestimated the geotechnical capacity by 44% with a COV of 52%. Table 21 shows a summary of the load ratio results based on the hammer rated energy.

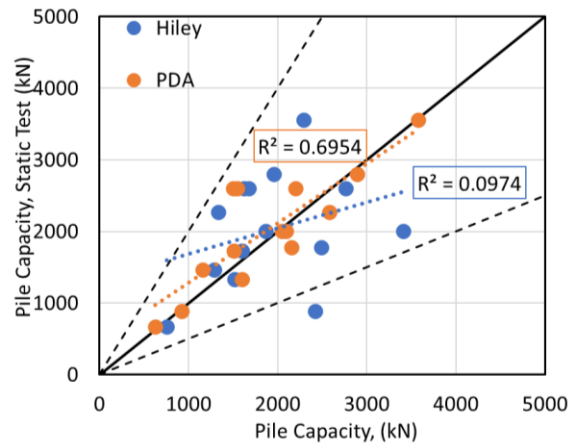
Figure 35 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based on the hammer rated energy. As shown in Figure 35a and Figure 35b, PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test. Table 20 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on the hammer rated energy.

Table 20 - Summary of the dataset of Hiley and PDA and comparison with the static pile load test based on the hammer rated energy

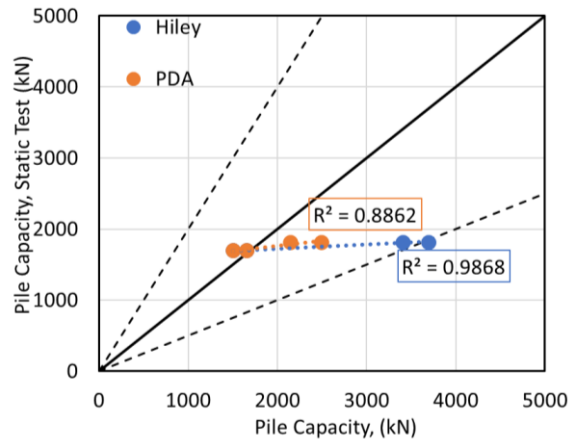
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to Static ULS Capacity	% of Error-PDA to Static ULS Capacity
Parameter	Energy, 30 kJ< E ≤ 90 kJ			
Number of Points	14			
Average	1928	1886	-8	5
Max	3407	3576	41	42
Min	756	623	-172	-21
R^2	0.1	0.7	---	---
Parameter	Energy, E kJ > 90 kJ			
Number of Points	4			
Average	2563	1946	-44	-10
Max	3693	2490	12	12
Min	1500	1500	-103	-37
R^2	0.99	0.89	---	---

Table 21 - Summary of the load ratio results of Hiley and PDA with respect to the static pile load test capacity based on the hammer rated energy

	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)	Load Ratio (Hiley/Static)	Load Ratio (PDA/Static)
Parameter	Energy, 30 kJ < E ≤ 90 kJ		Energy, E > 90 kJ	
No. of Points	14		4	
Average	1.08	0.95	1.44	1.1
Std Dev, σ	0.57	0.2	0.6	0.22
COV (%)	53	21	42	20
Max	2.72	1.21	2.03	1.37
Min	0.59	0.58	0.88	0.88

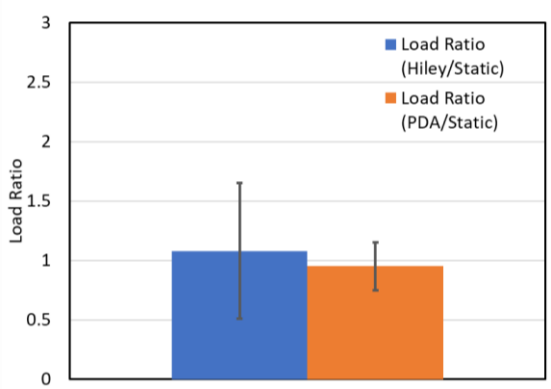


a) Energy, 30 < E ≤ 90 kJ

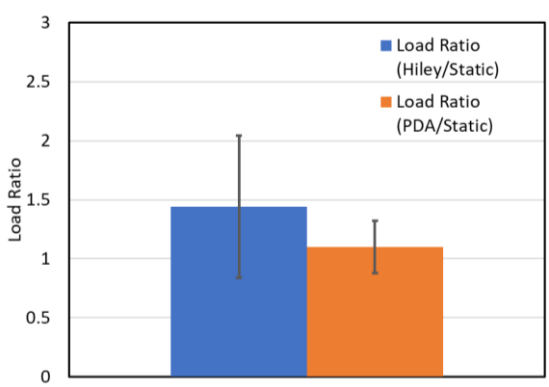


b) Energy, E > 90 kJ

Figure 33 - Comparison between the pile capacities of Hiley and PDA with respect to the static load test based on the hammer rated energy

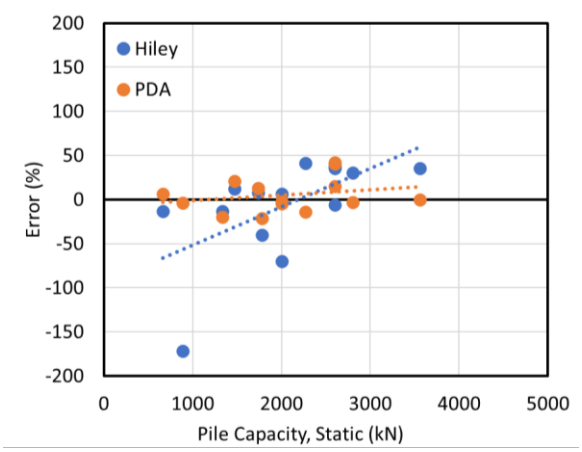


a) Energy, 30 < E ≤ 90 kJ

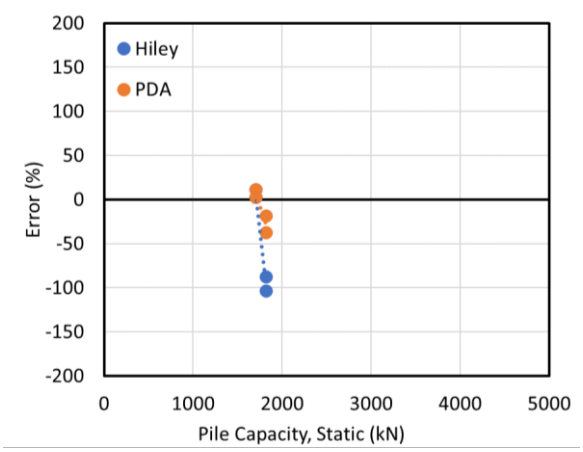


b) Energy, E > 90 kJ

Figure 34 - Comparison between Hiley and PDA Load ratio with respect to the static load test based on the hammer rated energy



a) Energy, 30 < E ≤ 90 kJ



b) Energy, E > 90 kJ

Figure 35 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the static load test based the hammer rated energy

6.3 Hiley and PDA Tests vs. FIDR ULS Resistance of Piles

The following section presents the comprehensive analysis comparing PDA and Hiley tests to the ULS resistance provided in the project's FIDR.

6.3.1 All Data

Figure 36 shows the comparison the between the pile capacities of Hiley and PDA with respect to the FIDR ultimate resistance loads based on all data considered simultaneously. The PDA tests data points were better aligned with 1:1 Line with most of the points within the 1:2 Line and 2:1 Line. The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing outside the 1:2 and 2:1 boundary. Table 22 shows a summary of the dataset of Hiley and PDA compared to the static pile load test based on all data.

Figure 37 shows the comparison between the Hiley and PDA load ratio with respect to the FIDR ultimate resistances. The results of PDA tests on average slightly underestimated the geotechnical capacity by 12% with COV of 38%, while Hiley tests on average overestimated the geotechnical capacity by 58% with COV of 72%. Table 23 shows a summary of the load ratio results based on all data.

Figure 38 shows the comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ultimate loads based on all data; Table 22 shows a summary of the percent error for both tests compared to FIDR ultimate resistances. PDA test results showed a lower range of error compared to Hiley results on average, however both tests showed a large range between the min and max value.

Table 22 - Summary of the dataset of Hiley and PDA compared to FIDR ultimate resistances based on all data

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Number of Points	264			
Average	4703	2610	-58	12
Max	9571	6600	50	84
Min	745	900	-450	-165

Table 23 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ultimate resistances based on all data

	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
No. of Points	264	
Average	1.58	0.88
Std Dev, σ	0.72	0.33
COV (%)	46	38
Max	5.5	2.65
Min	0.5	0.16

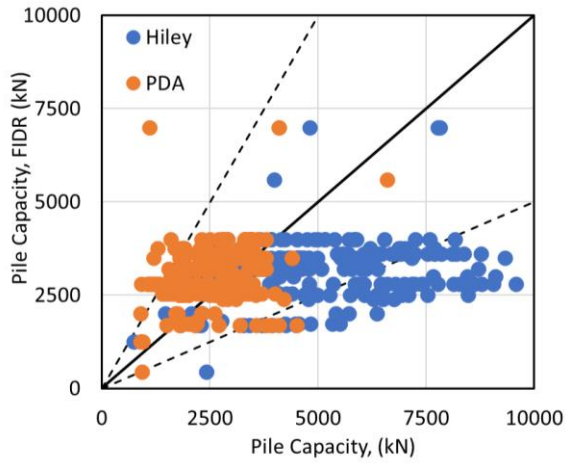


Figure 36 - Comparison between the pile capacities of Hiley and PDA with respect to the FIDR ultimate resistance based on all data

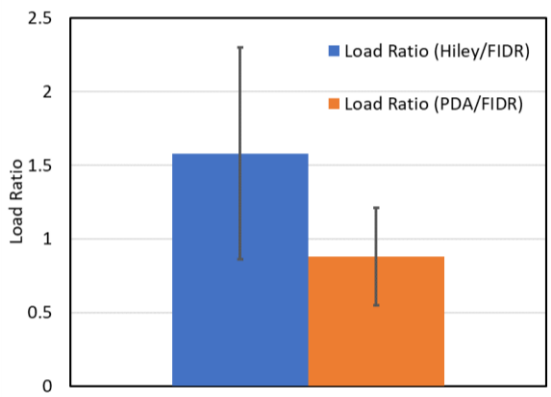


Figure 37 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ultimate resistance based on all data

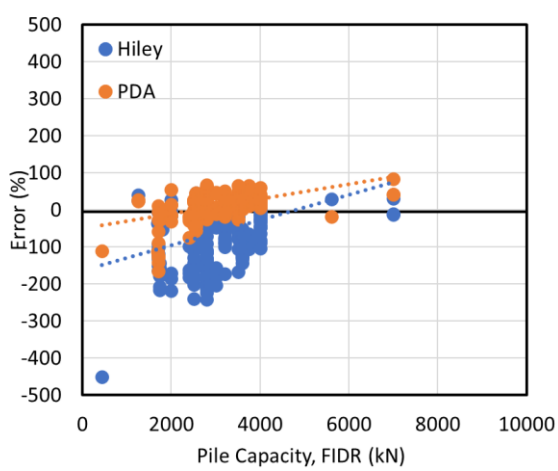


Figure 38 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ultimate resistance based on all data

6.3.2 Subsurface Condition and Load Transfer Mechanism

Figure 39 shows a comparison between the pile capacities estimated by Hiley and PDA tests with respect to the FIDR ultimate resistance based on subsurface conditions and load transfer mechanism. For end bearing – cohesionless soil (Figure 39b), end bearing – cohesive soil (Figure 39c), friction piles – layered soil (Figure 39d), and friction piles – cohesive piles (Figure 39f), PDA tests out-performed Hiley tests when comparing the estimated resistances to the FIDR ultimate resistance. The data points were better aligned along the 1:1 Line with almost all the points landing within the 1:2 and 2:1 line; the Hiley estimates showed significantly more scatter and more points landing outside the 1:2 and 2:1 line. For friction piles in cohesionless soils, Hiley tests show more data points closer to the 1:1 Line while the datapoints for PDA tests center around the 2:1 line. For end bearing piles in bedrock (Figure 39a), there is no correlation for either PDA or Hiley tests due to the extreme amounts of scatter. Table 24 shows a summary of the dataset of Hiley and PDA compared to the FIDR ultimate resistance based on the subsurface condition and load transfer mechanism.

Figure 40 shows the comparison between Hiley and PDA load ratio with respect to the FIDR ultimate resistance based on subsurface conditions and load transfer mechanism. For end bearing – cohesionless soil (Figure 40b), end bearing – cohesive soil (Figure 40c), friction piles – layered soil (Figure 40d), and friction piles – cohesive piles (Figure 40f), the average load ratio is closer to unity for PDA tests, with a small standard deviation compared to Hiley tests, for which the average load rations are typically around 1.5. For friction piles in cohesionless soil, the average load ratio for Hiley tests approaches unity while the load ratio for PDA tests is closer to 0.5, which suggests Hiley is better suited for this condition. For end bearing piles in bedrock, PDA tests on average underestimate the FIDR ultimate resistance by 25%, however based on the above discussion, there is no correlation; the same could be said of Hiley tests which greatly overestimate the load. Table 25 shows a summary of the statistical data concerning the load ratios.

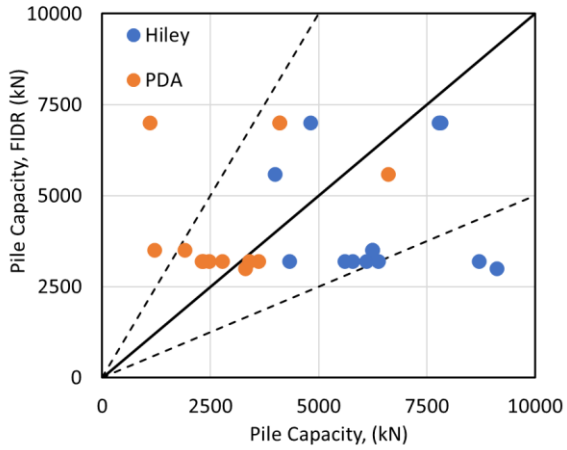
Figure 41 shows the distribution of percent-error between the Hiley and PDA estimates and FIDR ultimate resistances, while Table 25 shows the minimum, maximum, and average values for both tests. The distribution of points reflects those in Figure 39 with data points for end bearing piles in cohesionless soil and cohesive soil and friction piles in layered soil and cohesive soil, with more points centering around the 0% line compared to Hiley tests for which the data points typically fall below the 0% line. For friction piles in cohesionless soil, the distribution of points for both PDA and Hiley tests are much closer. For end bearing piles in bedrock, PDA tests data points are better centered around the 0% line compared to Hiley tests, however given the scatter of datapoints shown in Figure 39a, no correlation exists.

Table 24 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on subsurface conditions and load transfer mechanism

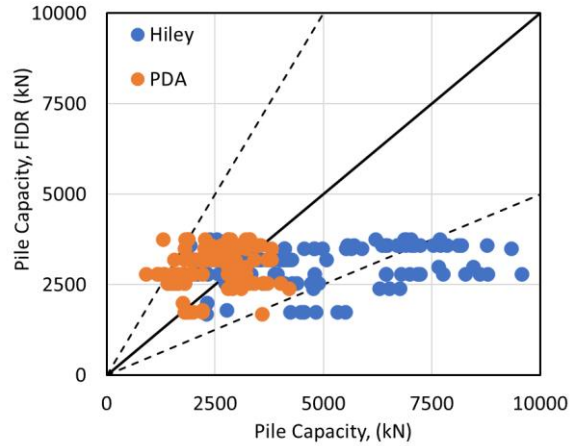
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	End Bearing Piles - Bedrock			
Number of Points	13			
Average	6372	3013	-67	25
Max	9105	6600	31	84
Min	3989	1100	-204	-18
Parameter	End Bearing Piles – Cohesionless Soil			
Number of Points	133			
Average	4592	2556	-53	15
Max	9571	4200	50	68
Min	1400	905	-242	-112
Parameter	End Bearing Piles – Cohesive Soil			
Number of Points	69			
Average	5035	2682	-71	12
Max	9057	4400	33	55
Min	2345	1400	-239	-42
Parameter	Friction Piles – Layered Soil Strata			
Number of Points	31			
Average	4423	2649	-54	6
Max	7845	4500	7	60
Min	2420	925	-450	-165
Parameter	Friction Piles – Cohesionless			
Number of Points	20			
Average	3064	1772	3	45
Max	5881	2850	50	65
Min	1687	1050	-68	19
Parameter	Friction Piles – Cohesive			
Number of Points	32			
Average	4851	2622	-65	11
Max	8376	4400	40	55
Min	745	900	-218	-30

Table 25 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on subsurface conditions and load transfer mechanism

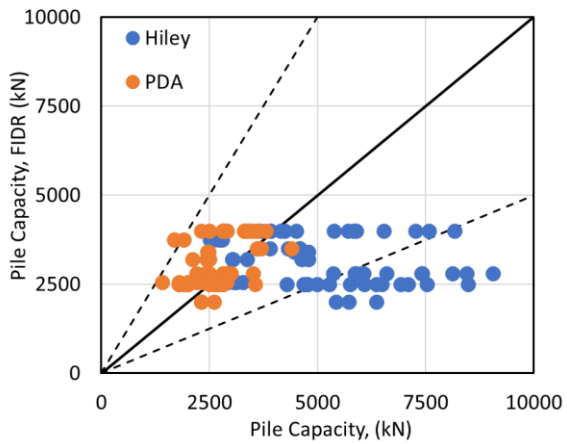
	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	End Bearing – Bedrock		End Bearing – Cohesionless Soil		End Bearing – Cohesive Soil	
No. of Points	13		133		69	
Average	1.67	0.75	1.53	0.85	1.71	0.88
Std Dev, σ	0.69	0.31	0.7	0.27	0.75	0.21
COV (%)	41	41	46	32	44	24
Max	3.04	1.18	3.42	2.12	3.39	1.42
Min	0.69	0.16	0.5	0.32	0.67	0.45
Parameter	Friction Piles – Layered Soil		Friction Piles – Cohesionless Soil		Friction Piles – Cohesive Soil	
No. of Points	31		20		32	
Average	1.54	0.94	0.97	0.55	1.65	0.89
Std Dev, σ	0.85	0.54	0.3	0.15	0.67	0.22
COV (%)	55	57	31	27	41	25
Max	5.5	2.65	1.68	0.81	3.18	1.3
Min	0.93	0.4	0.5	0.35	0.6	0.45



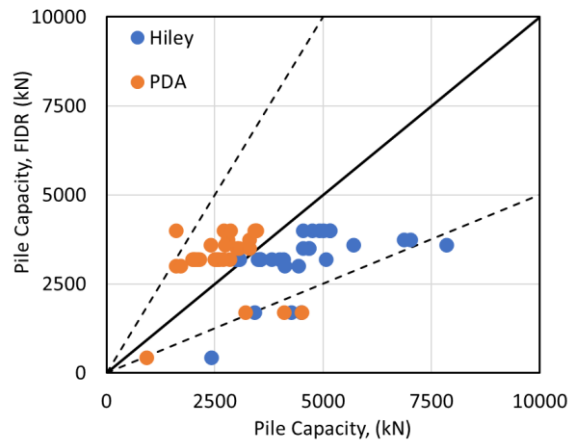
a) End Bearing – Bedrock



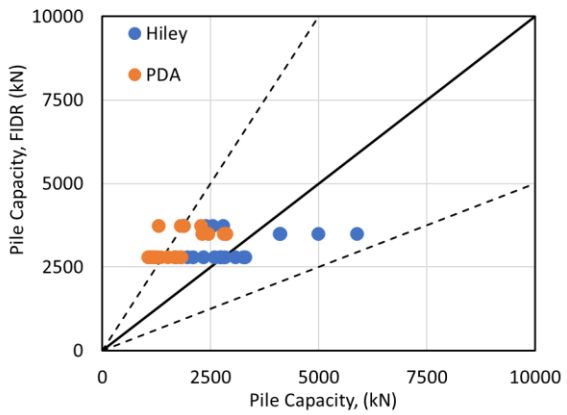
b) End Bearing – Cohesionless Soil



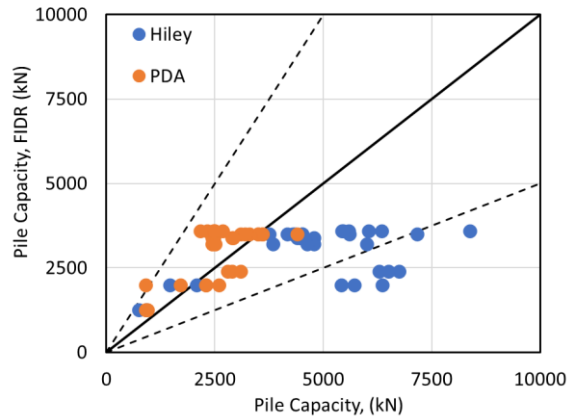
c) End Bearing – Cohesive Soil



d) Friction Piles – Layered Soil

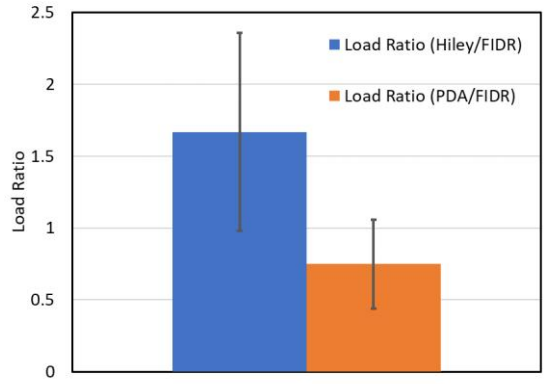


e) Friction Piles – Cohesionless Soil

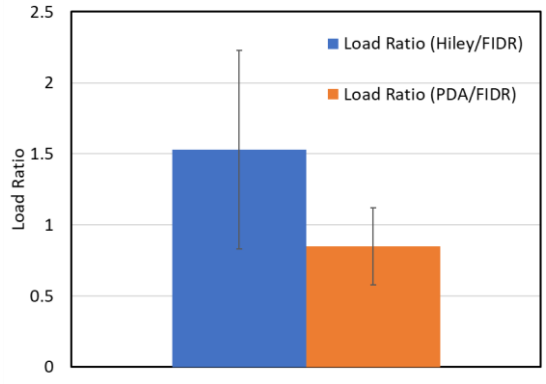


f) Friction Piles – Cohesive Soil

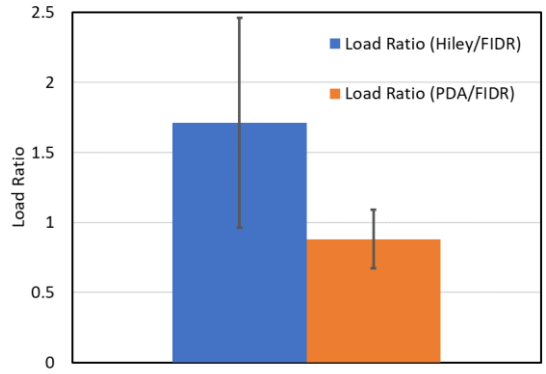
Figure 39 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on subsurface conditions and load transfer mechanism



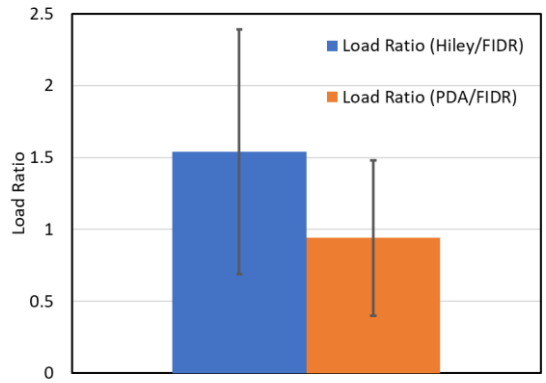
a) End Bearing – Bedrock



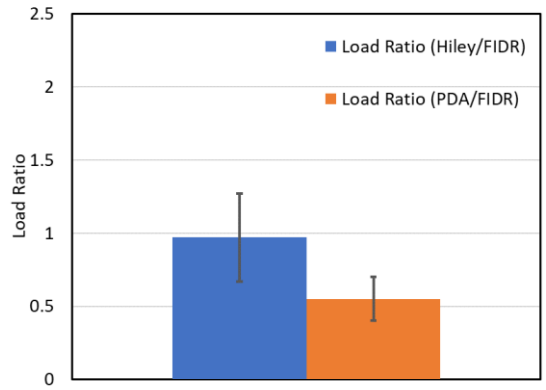
b) End Bearing – Cohesionless Soil



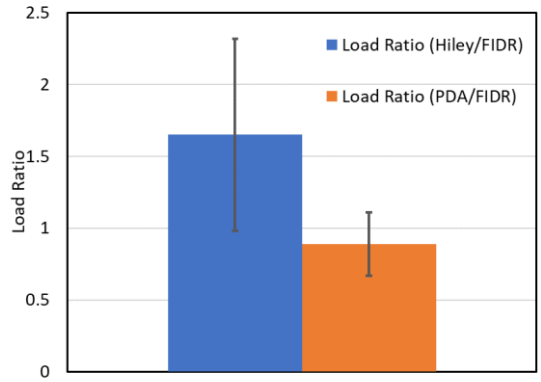
c) End Bearing – Cohesive Soil



d) Friction Piles – Layered Soil

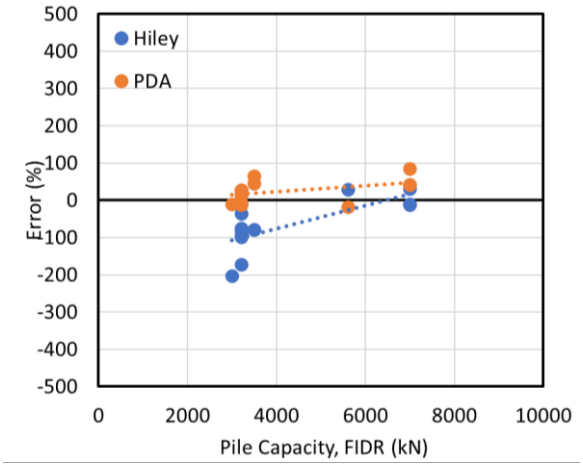


e) Friction Piles – Cohesionless Soil

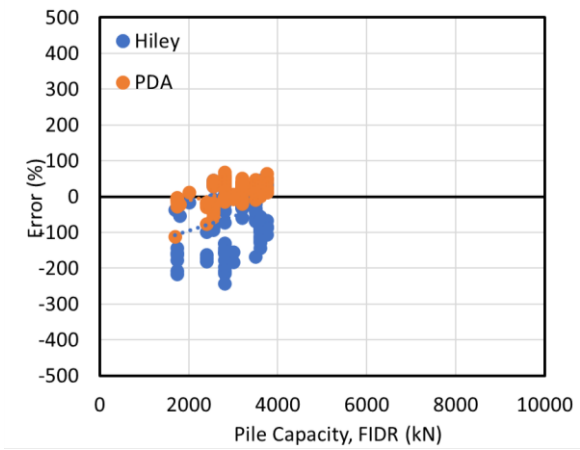


f) Friction Piles – Cohesive Soil

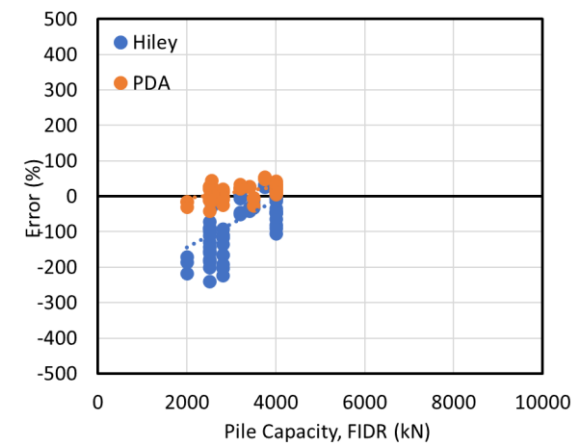
Figure 40 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on subsurface conditions and load transfer mechanism



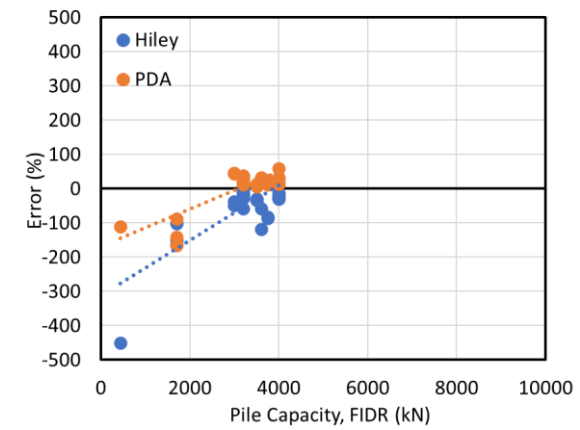
a) End Bearing – Bedrock



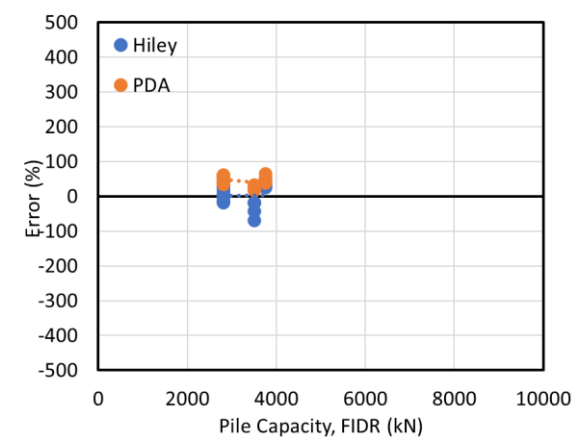
b) End Bearing – Cohesionless Soil



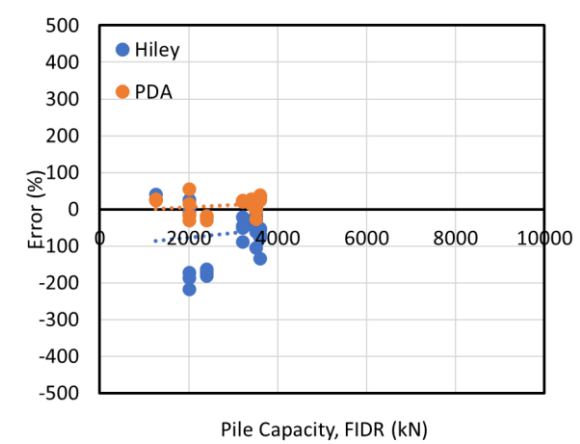
c) End Bearing – Cohesive Soil



d) Friction Piles – Layered Soil



e) Friction Piles – Cohesionless Soil



f) Friction Piles – Cohesive Soil

Figure 41 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on subsurface conditions and load transfer mechanism

6.3.3 Pile Inclination

Figure 42 shows a comparison between the estimated Hiley and PDA resistance and the FIDR ultimate resistance based on pile verticality. For vertical piles, PDA tests show better distribution along the 1:1 line with the majority of data points occurring within the 1:2 and 2:1 line. Hiley tests data points have a much greater amount of scatter with considerably more points landing below the 1:2 line indicating that Hiley tests overestimate the target ultimate resistance provided in FIDRs. For battered piles, PDA and Hiley tests show similar distributions of data points and scatter with most points occurring within the 1:2 and 2:1 line. Table 26 shows a summary of the dataset of Hiley and PDA compared to the FIDR ultimate resistance based on the pile inclination.

Figure 43 shows the average load ratio and standard deviation for the estimated Hiley and PDA resistance over the FIDR ultimate resistance. For PDA tests, the estimated resistances on average are closer to unity, underestimated the load by 15% with a COV of 31% for vertical piles and overestimated the load by 2% with a COV of 51% for battered piles. The Hiley estimated resistance on average are much higher than the FIDR provided values, overestimating the resistance by 60% with a COV of 47% for vertical piles and 47% with a COV of 41% for battered piles. Table 27 shows a summary of the statistical data concerning the load ratios.

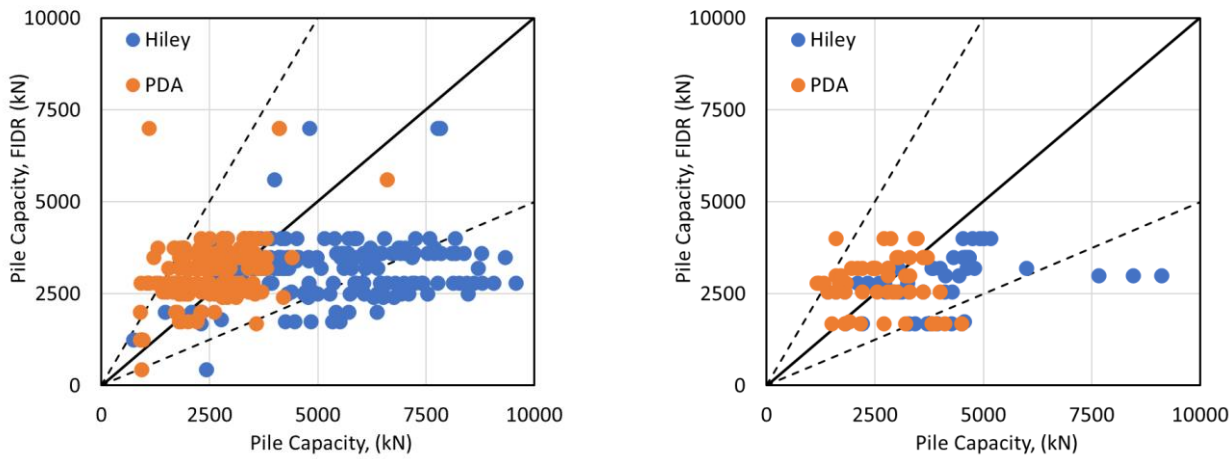
Figure 44 shows the distribution of percent-difference between the Hiley and PDA estimates and FIDR ultimate resistances, while Table 26 shows the min, max, and average values for both tests. The data points for PDA are much closer to the 0% line compared to Hiley for vertical piles, while showing a similar distribution for battered piles. However, for both cases, Hiley tests seem to on average overestimate the resistance of piles whereas PDA tests are closer to the same value.

Table 26 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on pile inclination

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	Vertical Piles			
Number of Points	214			
Average	4874	2604	-60	15
Max	9571	6600	50	84
Min	745	900	-450	-112
Parameter	Battered Piles			
Number of Points	50			
Average	3972	2634	-47	-2
Max	9105	4500	45	60
Min	1400	1165	-204	-165

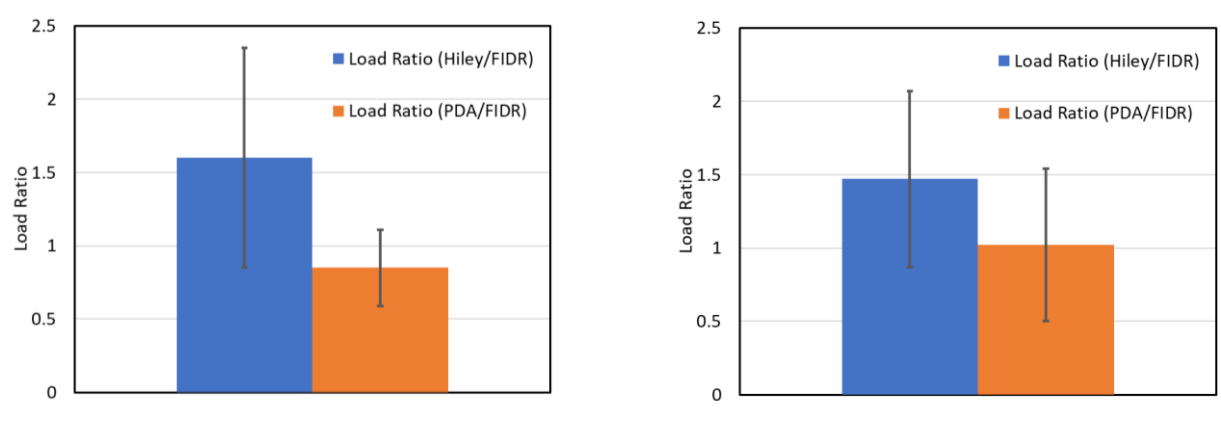
Table 27 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on pile inclination

	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	Vertical Piles		Battered Piles	
No. of Points	214		50	
Average	1.6	0.85	1.47	1.02
Std Dev, σ	0.75	0.26	0.6	0.52
COV (%)	47	31	41	51
Max	5.5	2.12	3.04	2.65
Min	0.5	0.16	0.55	0.4



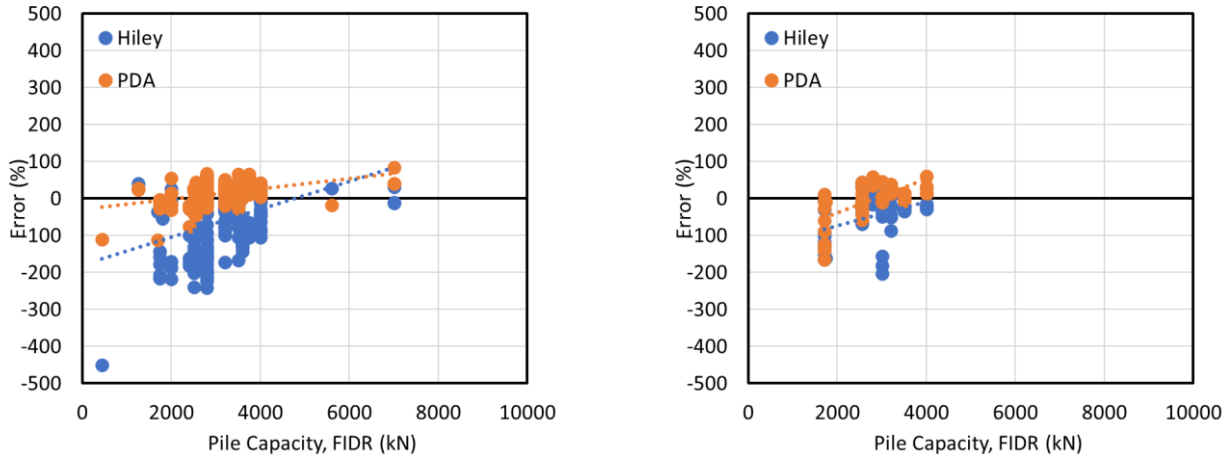
a) Vertical Piles b) Battered Piles

Figure 42 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on pile inclination



a) Vertical Piles b) Battered Piles

Figure 43 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on pile inclination



a) Vertical Piles b) Battered Piles

Figure 44 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on pile inclination

6.3.4 Pile Type

Figure 45 shows a comparison the between the pile capacities estimated by Hiley and PDA tests with respect to the FIDR ultimate resistance based on pile type. The analysis was divided in to HP310 piles (HP310x110 and HP310 x 132), HP360x174 piles, and pipe piles. Note that the HP310 x 79 piles were excluded from this analysis as the FIDR only provided ULS resistances for pipe piles with no provision of substituting pipe piles with H-Piles.

For HP310x110 and HP360x174 piles PDA tests show better distribution along the 1:1 line with the majority of data points occurring within the 1:2 and 2:1 line. Hiley tests data points have a much greater amount of scatter with considerably more points landing below the 1:2 line indicating that Hiley tests overestimate the target ultimate resistance provided in FIDRs. For pipe piles, both Hiley and PDA tests are closely distributed along the 1:1 line, however it is difficult to assess the actual performance of pipe piles with this low sample size. Table 28 shows a summary of the dataset of Hiley and PDA compared to the FIDR ultimate resistance based on the pile type.

Figure 46 shows the average load ratio and standard deviation for the estimated Hiley and PDA resistance over the FIDR ultimate resistance. For PDA tests, the estimated resistance on average reaches unity with load ratios ranging between 0.87 and 0.9 between the three piles types The COV was 40% for HP310 piles, 26% for HP360 piles, and 28% for pipe piles suggesting more reliability for HP310 and pipe piles. For Hiley tests, the average load ratio for HP310 and HP360 piles was 1.45 and 2.04 suggesting that Hiley tests greatly overpredict the FIDR ultimate resistance. Conversely, the load ratio for pipe piles was 0.68 indicating Hiley tests greatly underpredicts the capacity. Table 29 shows a summary of the statistical data concerning the load ratios.

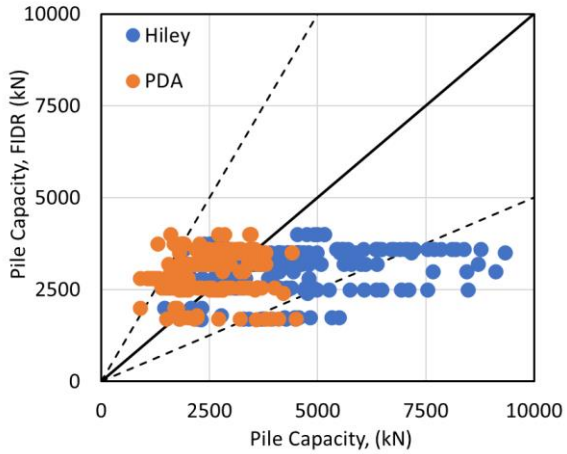
Figure 47 shows the distribution of percent-error between the Hiley and PDA estimates and FIDR ultimate resistances, while Table 28 shows the min, max, and average values for both tests. The data points for PDA are much closer to the 0% line compared to Hiley for all three cases, however for both tests the distribution of points is scattered, although PDA tests are generally less scattered Hiley tests.

Table 28 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on pile type

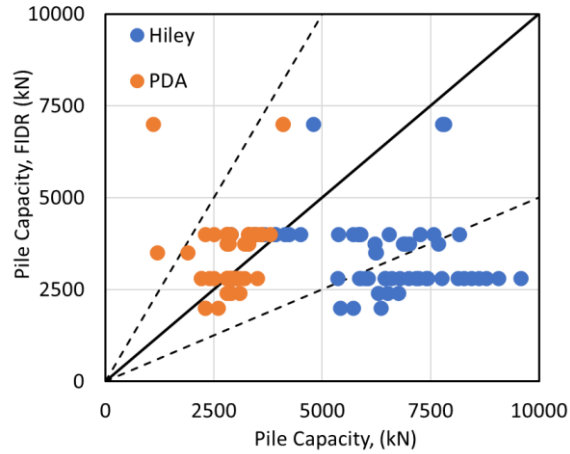
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	HP310x110 / HP310 x 132			
Number of Points	205			
Average	4292	2536	-45	13
Max	9327	4500	50	68
Min	1400	900	-239	-165
Parameter	HP360 x 174			
Number of Points	55			
Average	6432	2904	-104	10
Max	9571	4100	31	84
Min	2900	1100	-242	-30
Parameter	Pipe Piles			
Number of Points	3			
Average	1884	2817	32	11
Max	3989	6600	40	28
Min	745	900	26	-18

Table 29 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on pile type

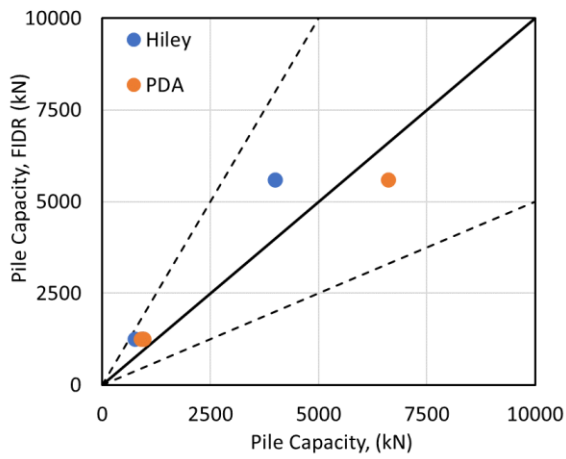
	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	HP310x110 / HP310 x 132		HP360 x 174		Pipe Piles	
No. of Points	205		55		3	
Average	1.45	0.87	2.04	0.9	0.68	0.89
Std Dev, σ	0.61	0.35	0.74	0.23	0.07	0.25
COV (%)	42	40	36	26	10	28
Max	3.39	2.65	3.42	1.3	0.74	1.18
Min	0.5	0.32	0.69	0.16	0.6	0.72



a) HP310x110 / HP310 x 132

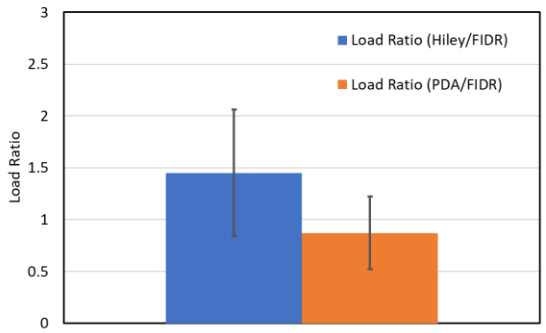


b) HP360 x 174

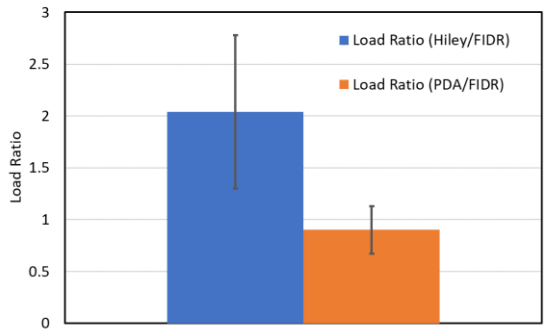


c) Pipe Piles

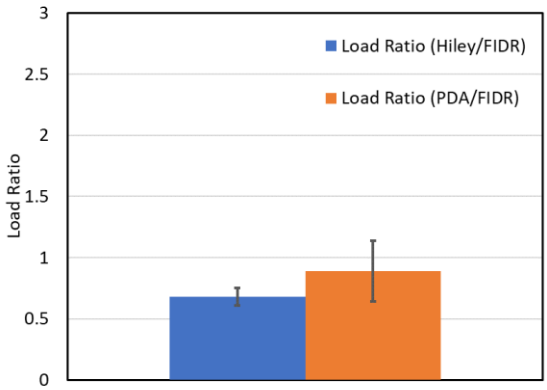
Figure 45 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on pile type



a) HP310x110 / HP310 x 132

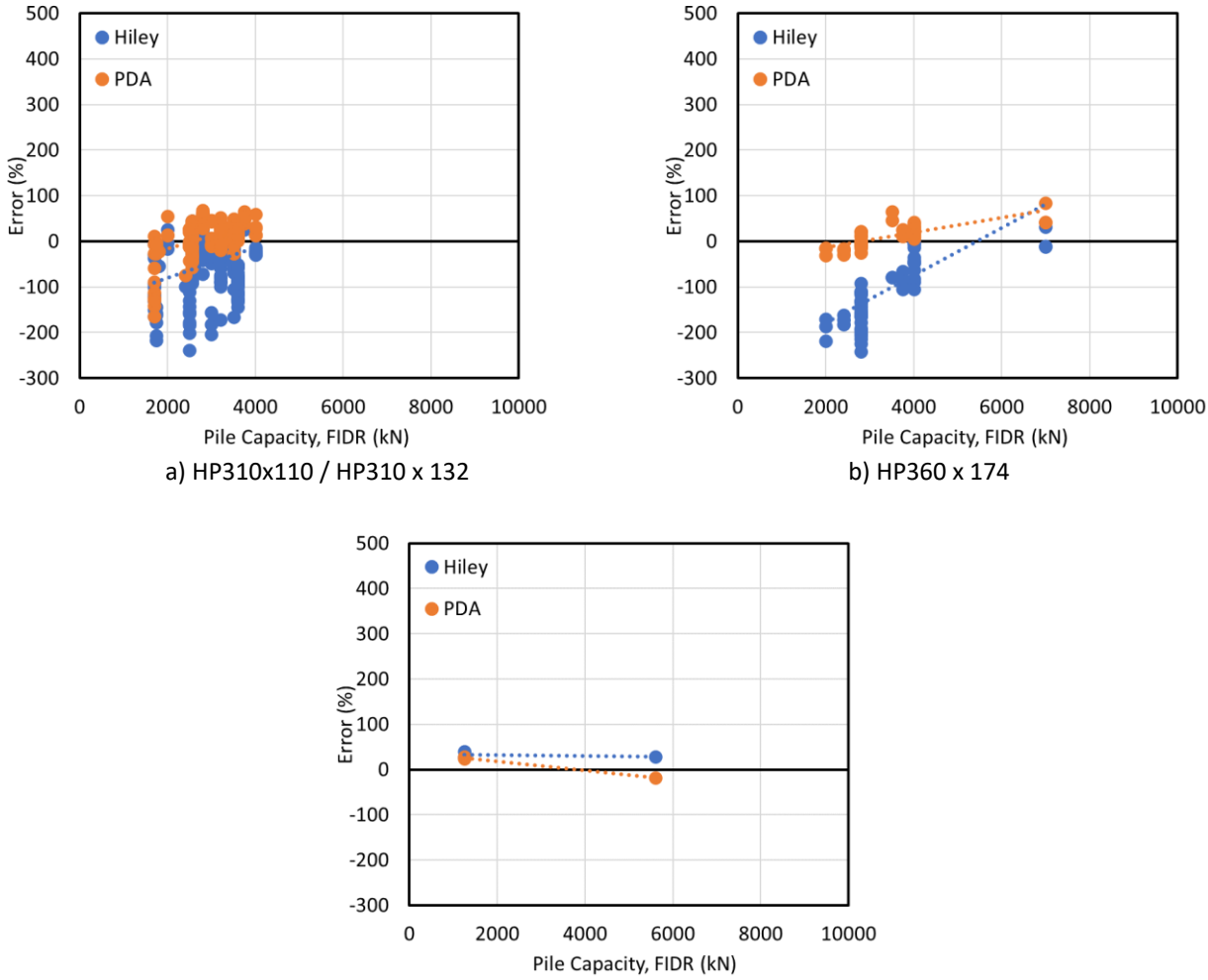


b) HP360 x 174



c) Pipe Piles

Figure 46 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on pile type



a) HP310x110 / HP310 x 132

b) HP360 x 174

c) Pipe Piles

Figure 47 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on pile type

6.3.5 Pile Embedment Length

Figure 48 shows a comparison between the estimated Hiley and PDA resistance and the FIDR ultimate resistance based on pile embedment length. For vertical piles, PDA tests show better distribution along the 1:1 line with the majority of data points occurring within the 1:2 and 2:1 line for all pile lengths, with no significant differences in distribution for all cases. Hiley tests data points have a much greater amount of scatter with considerably more points landing below the 1:2 line indicating that Hiley tests overestimate the target ultimate resistance provided in FIDRs. However, as the pile length increases, the level of scatter appears to decrease, and the points distribute closer to the 1:1 line and above the 1:2 line. Table 30 shows a summary of the dataset of Hiley and PDA compared to the FIDR ultimate resistance based on pile embedment length.

Figure 49 shows the average load ratio and standard deviation for the estimated Hiley and PDA resistance over the FIDR ultimate resistance. For PDA tests, the average load ratio for piles under 36 m stays consistent between 0.88 and 0.89 with a COV of 30%, 46%, and 30% for piles under 12 m, piles between 12 and 24 m, and piles between 24 and 36 m, respectively. For piles over 36 m, the average load ratio reduced to 0.75 but with a COV of 12% indicating less scatter in this embedment length range. For Hiley tests, a trend is observed where the load ratio decreases and approaches unity as the embedment length increases, starting

at a load ratio of 2 for piles with less than 12 m of embedment and 1.14 for piles over 36 m of embedment. The COV also decreases as the embedment length increases indicating better reliability for piles with deeper embedment. Table 31 shows a summary of the statistical data concerning the load ratios.

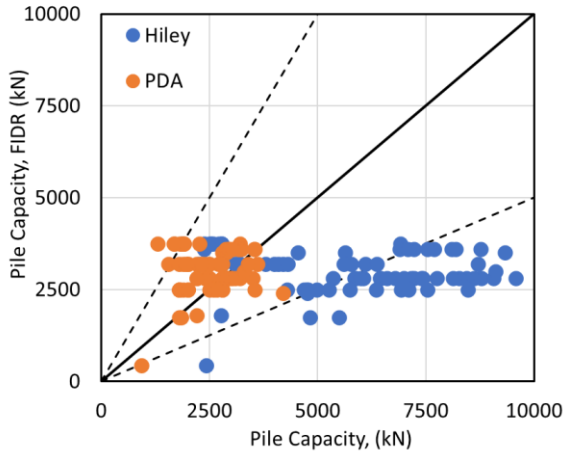
Figure 50 shows the distribution of percent-difference between the Hiley and PDA estimates and FIDR ultimate resistances, while Table 30 shows the min, max, and average values for both tests. Similar to load ratios, for PDA tests the average percent error stays consistently low for piles under 36 m and increases for piles over 36 m. The minimum and maximum range is also approximately consistent for piles under 36 m. For Hiley tests, the percentage of error becomes smaller with longer pile embedment. The minimum/maximum range also decreases with increasing embedment.

Table 30 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on pile embedment length

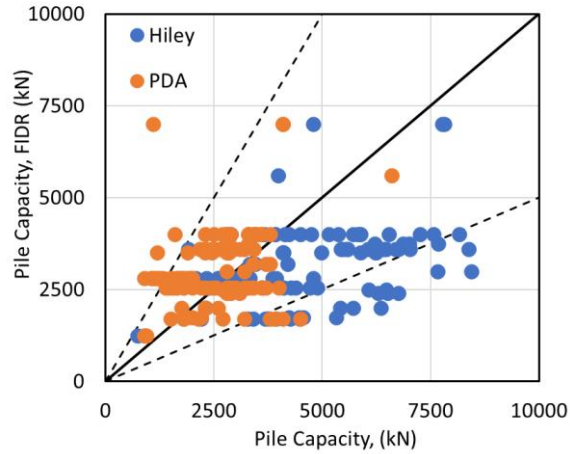
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	Embedment Length, L ≤ 12 m			
Number of Points	79			
Average	5660	2576	-100	11
Max	9571	4200	50	65
Min	1870	925	-450	-110
Parameter	Embedment Length, 12 < L ≤ 24 m			
Number of Points	121			
Average	4386	2547	-49	11
Max	8447	6600	47	84
Min	745	900	-218	-165
Parameter	Embedment Length, 24 < L ≤ 36 m			
Number of Points	43			
Average	4382	2959	-29	12
Max	7845	4400	27	55
Min	1466	900	-118	-112
Parameter	Embedment Length, 36 < L ≤ 60 m			
Number of Points	23			
Average	3662	2408	-14	25
Max	5070	2965	7	38
Min	2973	1980	-58	7

Table 31 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on pile embedment length

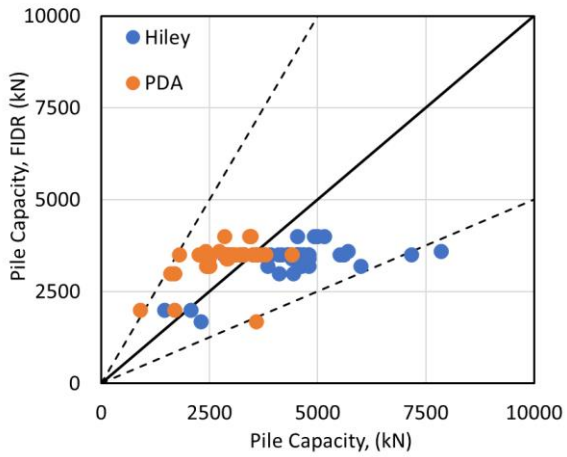
	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	Embedment Length, E ≤ 12 m		Embedment Length, 12 < L ≤ 24 m	
No. of Points	79		121	
Average	2	0.89	1.49	0.89
Std Dev, σ	0.89	0.27	0.63	0.41
COV (%)	45	30	42	46
Max	5.5	2.1	3.18	2.65
Min	0.5	0.35	0.53	0.16
Parameter	Embedment Length, 24 < L ≤ 36 m		Embedment Length, 36 < L ≤ 60 m	
No. of Points	43		23	
Average	1.29	0.88	1.14	0.75
Std Dev, σ	0.3	0.26	0.15	0.09
COV (%)	23	30	13	12
Max	2.18	2.12	1.58	0.93
Min	0.73	0.45	0.93	0.62



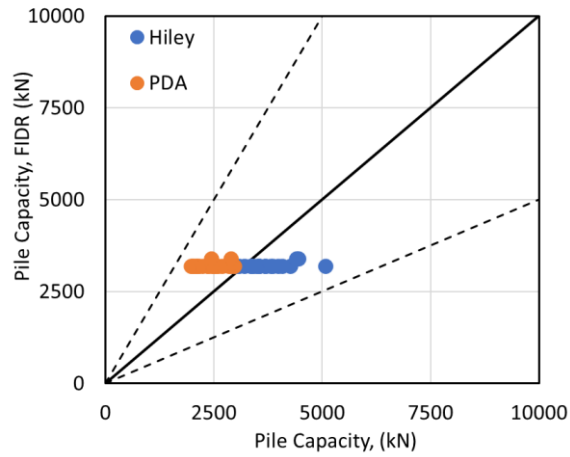
a) Embedment Length, E ≤ 12 m



b) Embedment Length, 12 < L ≤ 24 m

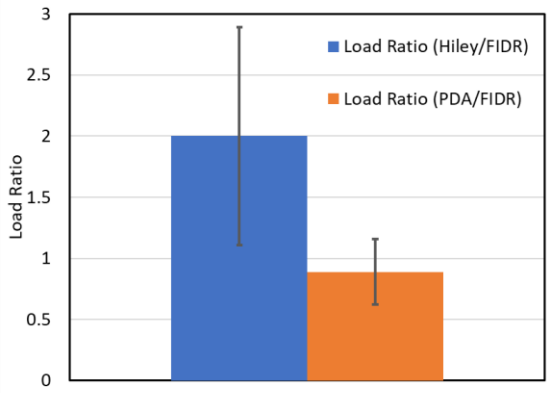


c) Embedment Length, 24 < L ≤ 36 m

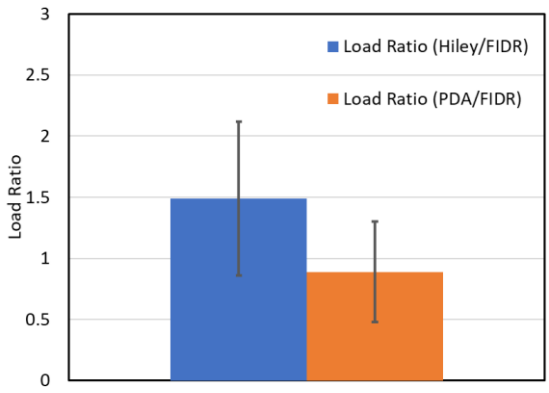


d) Embedment Length, 36 < L ≤ 60 m

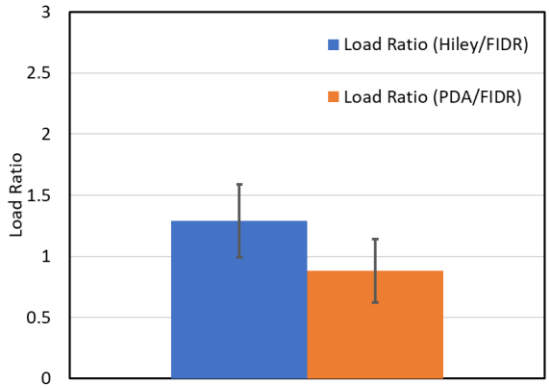
Figure 48 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on pile embedment length



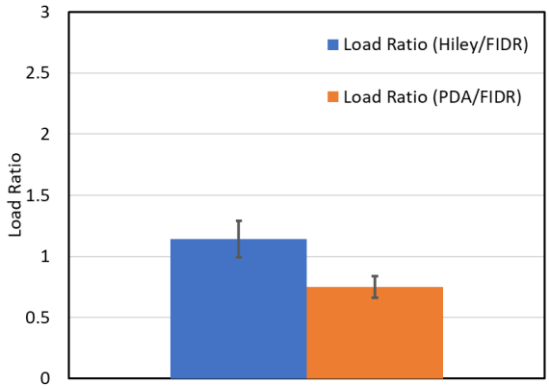
a) Embedment Length, E ≤ 12 m



b) Embedment Length, 12 < L ≤ 24 m

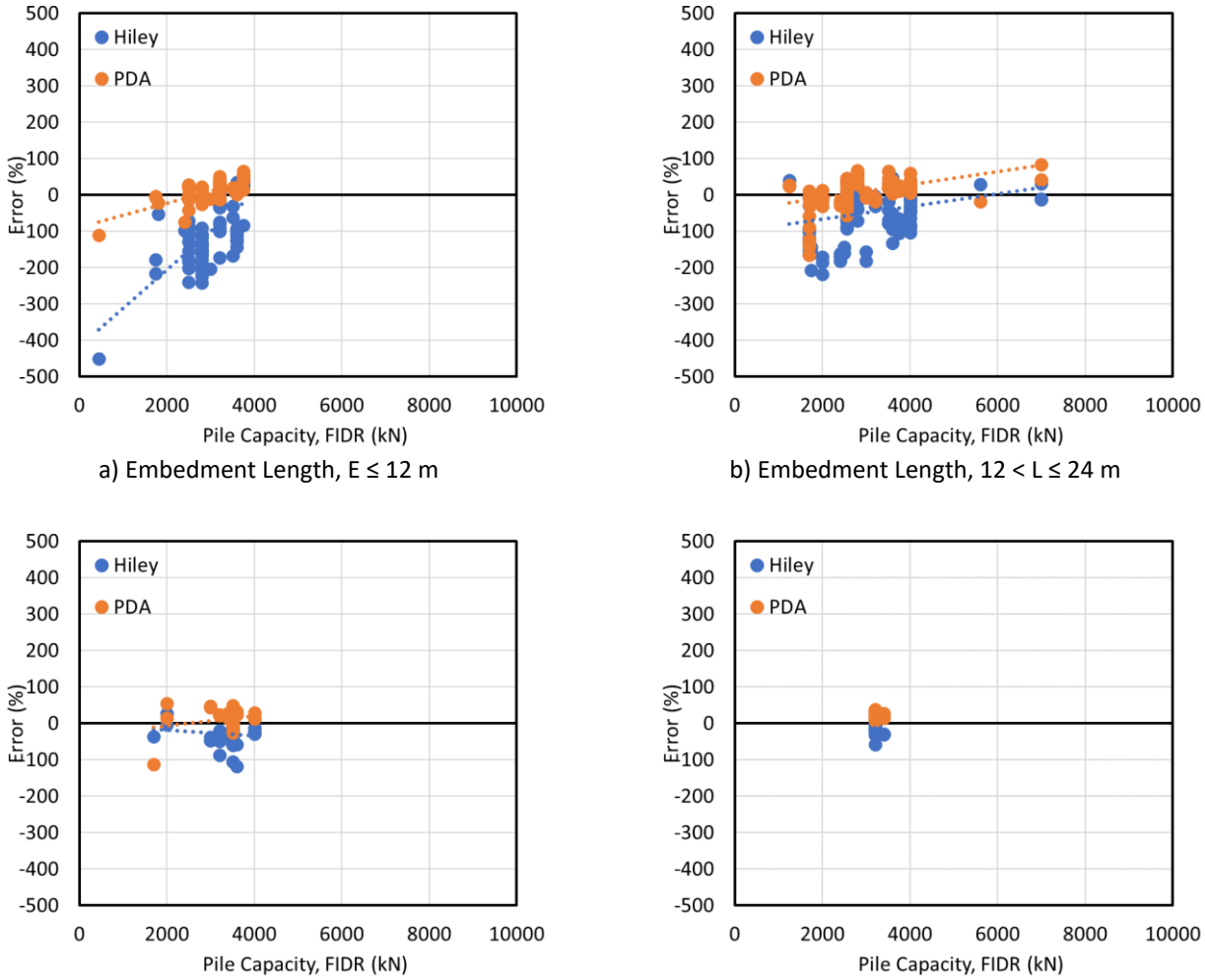


c) Embedment Length, 24 < L ≤ 36 m



d) Embedment Length, 36 < L ≤ 60 m

Figure 49 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on pile embedment length



a) Embedment Length, E ≤ 12 m

b) Embedment Length, 12 < L ≤ 24 m

c) Embedment Length, 24 < L ≤ 36 m

d) Embedment Length, 36 < L ≤ 60 m

Figure 50 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on pile embedment length

6.3.6 Pile Splice

Figure 51 shows a comparison between the estimated Hiley and PDA resistance and the FIDR ultimate resistance based on whether the pile was spliced. For spliced piles, PDA and Hiley tests appear to have similar amounts of scatter, however most points land above the 1:1 line for PDA tests and below the 1:1 line for Hiley tests. For piles which have not been spliced, PDA tests show better distribution along the 1:1 line with the majority of data points occurring within the 1:2 and 2:1 line. Hiley tests data points have a much greater amount of scatter with considerably more points landing below the 1:2 line indicating that Hiley tests overestimate the target ultimate resistance provided in FIDRs. Table 32 shows a summary of the dataset of Hiley and PDA compared to the FIDR ultimate resistance based on pile splice.

Figure 52 shows the average load ratio and standard deviation for the estimated Hiley and PDA resistance over the FIDR ultimate resistance. For PDA tests, the ratio is closer to unit for both piles that have been spliced and those which have not, however for both cases PDA underestimates the resistance by 17% and 9% respectively. Hiley tests on average overestimate the ULS resistance load by 38% for piles which have been spliced and 71% for piles which have not. The level of scatter in load ratios is

similar for both PDA and Hiley tests, with Hiley only having a 6 to 7% higher scatter than PDA tests. Table 33 shows a summary of the statistical data concerning the load ratios.

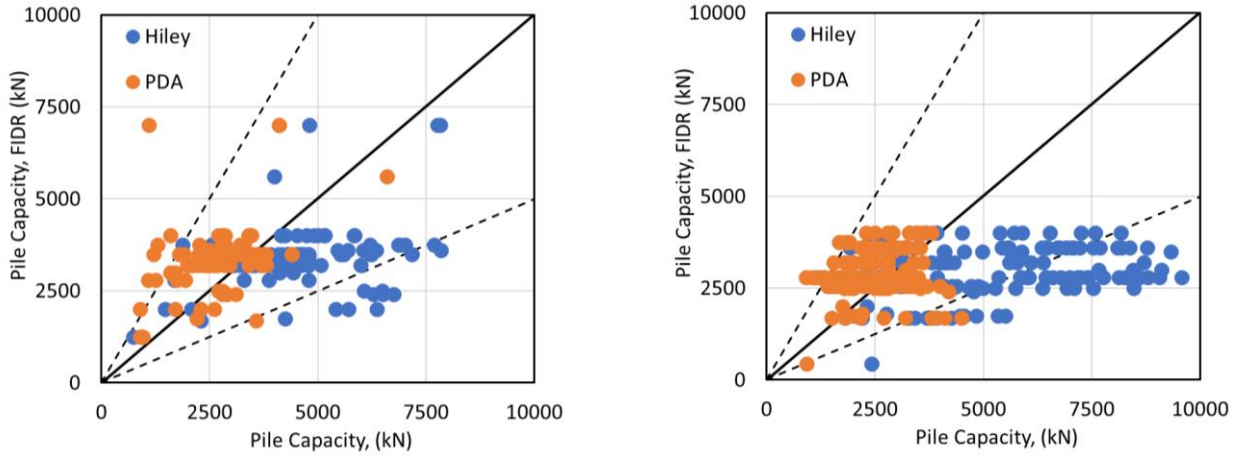
Figure 53 shows the distribution of percent-difference between the Hiley and PDA estimates and FIDR ultimate resistances, while Table 32 shows the min, max, and average values for both tests. The data points for PDA are much closer to the 0% line compared to Hiley for both spliced piles and non-spliced piles, with an approximately even distribution on either side. The data points for Hiley tests typically fell below the 0% line for both cases. While both tests showed large amounts of scatter, PDA tests are more likely to be approximately while Hiley tests tend to overestimate the capacity; this is reflected in the load ratios.

Table 32 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on pile splice

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	With Splice			
Number of Points	104			
Average	4497	2712	-38	17
Max	7845	6600	50	84
Min	745	900	-218	-112
Parameter	Without Splice			
Number of Points	160			
Average	4837	2543	-71	9
Max	9571	4500	47	68
Min	1400	905	-450	-165

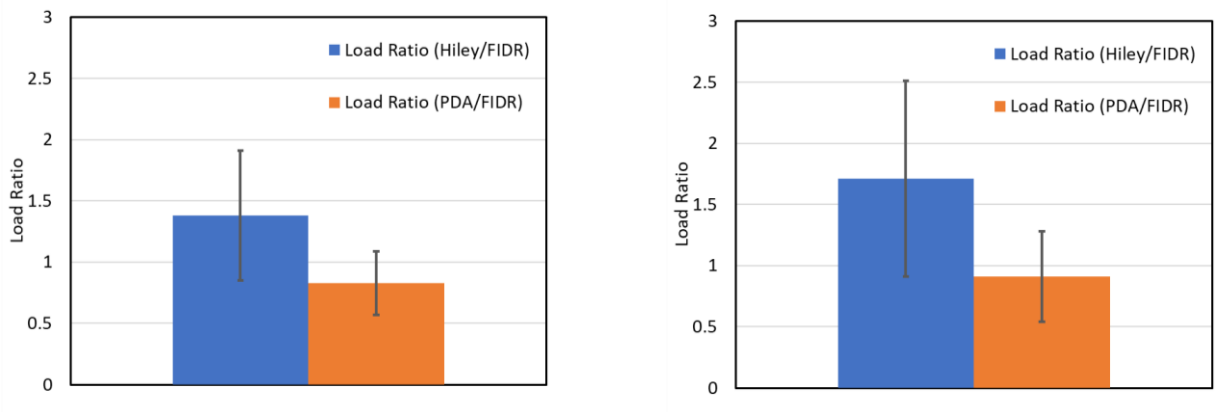
Table 33 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on pile splice

	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	With Splice		Without Splice	
No. of Points	104		160	
Average	1.38	0.83	1.71	0.91
Std Dev, σ	0.53	0.26	0.8	0.37
COV (%)	38	31	47	41
Max	3.18	2.12	5.5	2.65
Min	0.5	0.16	0.53	0.32



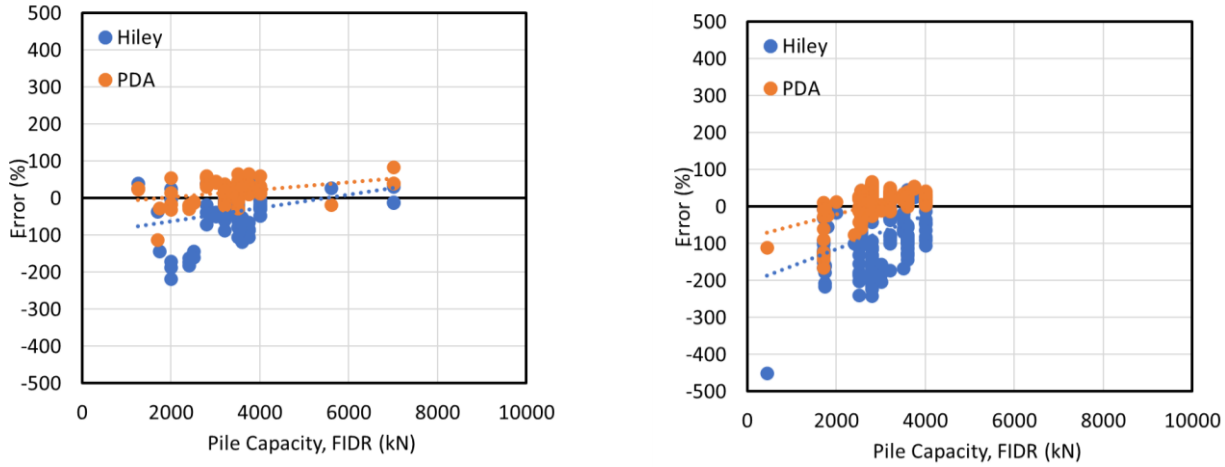
a) With Splice b) Without Splice

Figure 51 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on pile splice



a) With Splice b) Without Splice

Figure 52 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on pile splice



a) With Splice b) Without Splice

Figure 53 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on pile splice

6.3.7 Pile Driving Event

Figure 54 shows a comparison between the estimated Hiley and PDA resistance and the FIDR ultimate resistance based on pile driving event: end of initial drive (EOID), beginning of restrike (BOR), and end of restrike (EOR). For both PDA and Hiley tests, they did not show a difference in point distribution for different pile driving events. For PDA tests, the data points are distributed closer to the 1:1 line compared to Hiley tests. For PDA tests, the data points tend to fall above the 1:1 line indicating PDA tests underestimate the FIDR resistance whereas for Hiley tests the points fall below the 1:1 suggesting Hiley tests overestimate the FIDR resistance. Table 34 shows a summary of the dataset of Hiley and PDA compared to the FIDR ultimate resistance based on pile driving event.

Figure 55 shows the average load ratio and standard deviation for the estimated Hiley and PDA resistance over the FIDR ultimate resistance. PDA tests underestimate the FIDR ultimate resistance by with 21% with a COV of 35% for EOID and by 9% with a COV of 37% for BOR events; PDA tests appear to perform best under EOR events however the sample size for this case is low and may show similar distributions to the EOID and BOR events with more data points. Hiley tests have a much higher load ratio for all three events with large COV's compared to PDA indicating less accuracy and reliability in this test method. Table 35 shows a summary of the statistical data concerning the load ratios.

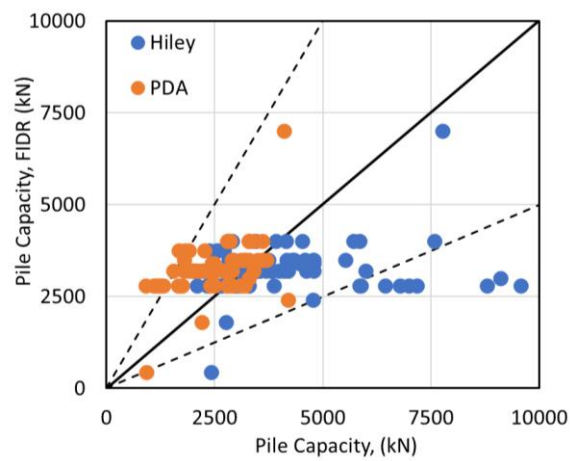
Figure 56 shows the distribution of percent-difference between the Hiley and PDA estimates and FIDR ultimate resistances, while Table 34 shows the min, max, and average values for both tests. The data points for PDA are much closer to the 0% line compared to Hiley for all three events, however for both tests the distribution of points is scattered, although PDA tests are generally less scattered than Hiley tests.

Table 34 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on pile driving event

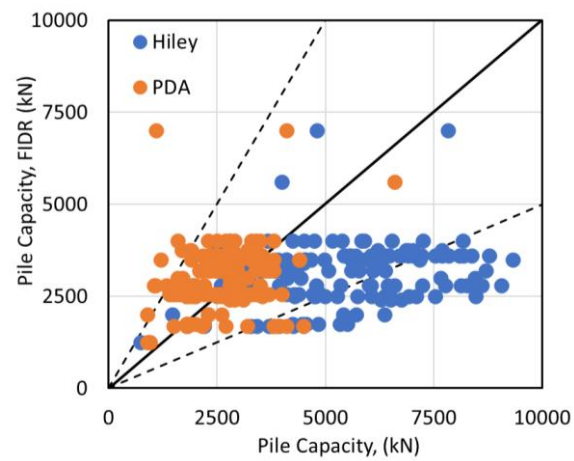
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	End of Initial Drive (EOID)			
Number of Points	74			
Average	4216	2495	-37	21
Max	9571	4200	37	68
Min	2086	905	-450	-110
Parameter	Beginning of Restrike (BOR)			
Number of Points	176			
Average	4965	2664	-68	9
Max	9327	6600	47	84
Min	745	900	-239	-165
Parameter	End of Restrike (EOR)			
Number of Points	7			
Average	4325	2439	-70	-5
Max	7420	3576	-4	30
Min	2073	1700	-165	-112

Table 35 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on pile driving event

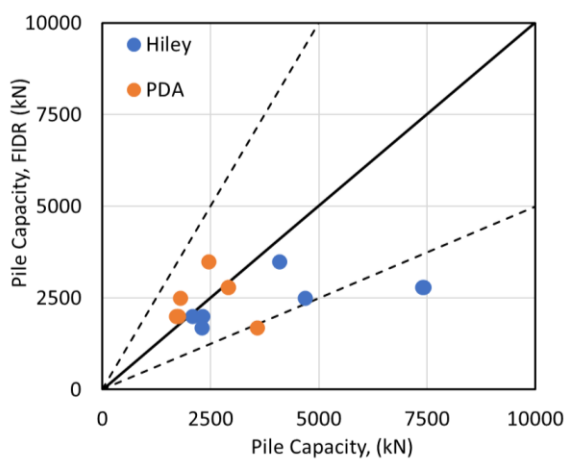
	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	End of Initial Drive (EOID)		Beginning of Restrike (BOR)		End of Restrike (EOR)	
No. of Points	74		76		7	
Average	1.37	0.79	1.68	0.91	1.7	1.05
Std Dev, σ	0.76	0.28	0.7	0.34	0.7	0.49
COV (%)	55	35	42	37	41	47
Max	5.5	2.1	3.39	2.65	2.65	2.12
Min	0.63	0.32	0.53	0.16	1.04	0.7



a) End of Initial Drive (EOID)

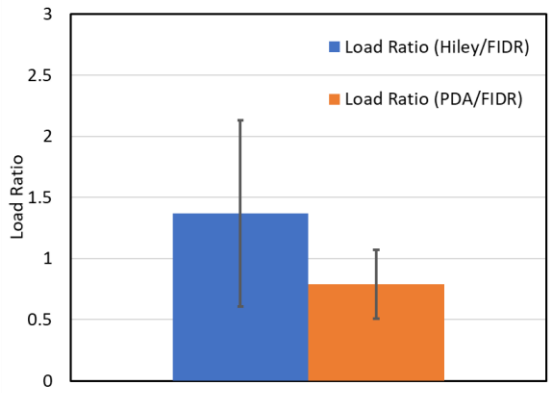


b) Beginning of Restrike (BOR)

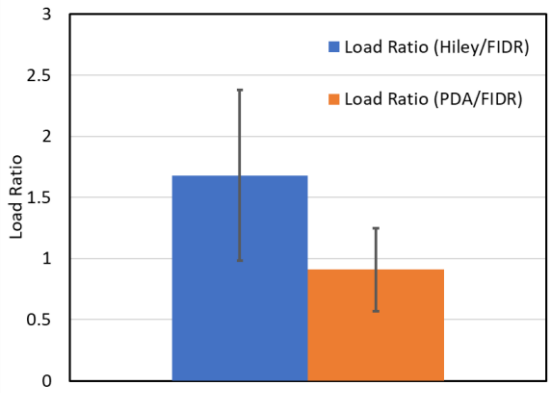


c) End of Restrike (EOR)

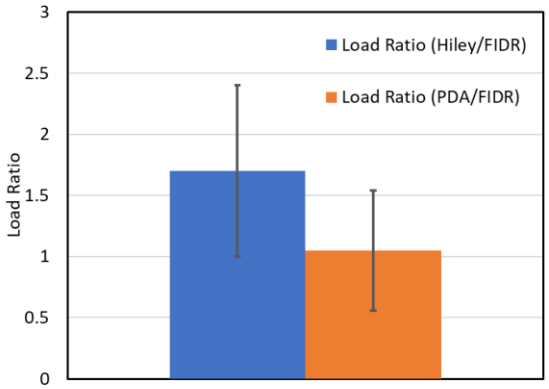
Figure 54 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on pile driving event



a) End of Initial Drive (EOID)

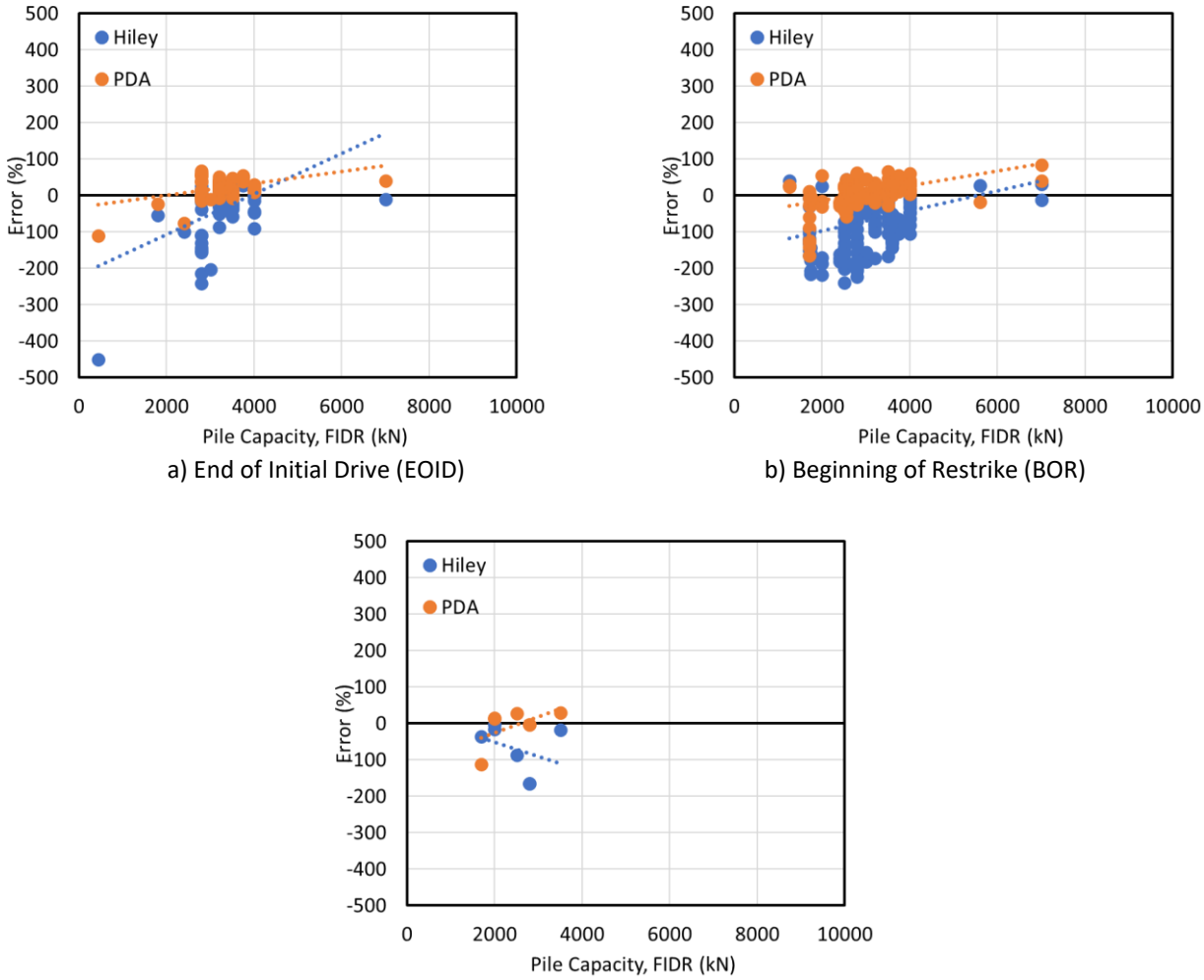


b) Beginning of Restrike (BOR)



c) End of Restrike (EOR)

Figure 55 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on pile driving event



a) End of Initial Drive (EOID)

b) Beginning of Restrike (BOR)

c) End of Restrike (EOR)

Figure 56 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on pile driving event

6.3.8 Hammer System

Figure 57 shows a comparison between the estimated Hiley and PDA resistance and the FIDR ultimate resistance based on hammer system, with diesel Hammers and drop Hammers being considered. For diesel hammers, PDA tests show better distribution along the 1:1 line with the majority of data points occurring within the 1:2 and 2:1 line. Hiley tests data points have a much greater amount of scatter with considerably more points landing below the 1:2 line indicating that Hiley tests overestimate the target ultimate resistance provided in FIDRs. For drop hammers, the data points are relatively equal for both PDA and Hiley tests, landing close to the 1:1 line indicating both tests are fairly reliable when trying to reach the target ultimate resistance. Table 36 shows a summary of the dataset of Hiley and PDA compared to the FIDR ultimate resistance based on pile hammer system.

Figure 58 shows the average load ratio and standard deviation for the estimated Hiley and PDA resistance over the FIDR ultimate resistance. For diesel hammers, the load ratio is closer to unity for PDA tests, underestimating the FIDR ultimate resistance by 12% with a COV of 39%. Hiley tests overestimated the FIDR ultimate resistance by 62% with a COV of 44%. For drop hammers,

the average load ratios are relatively close to each other (0.86 for Hiley and 0.84 for PDA) with low COV's of 9% and 7% for both PDA and Hiley tests, respectively. Table 37 shows a summary of the statistical data concerning the load ratios.

Figure 59 shows the distribution of percent-difference between the Hiley and PDA estimates and FIDR ultimate resistances, while Table 36 shows the min, max, and average values for both tests. The data points for PDA are much closer to the 0% line compared to Hiley for diesel hammers. Most of the points fell between the -100% line and 100% line for PDA and between the 0% and -200% line for Hiley. While both tests showed large amounts of scatter, PDA tests are more likely to be approximately while Hiley tests tend to overestimate the capacity; this is reflected in the load ratios.

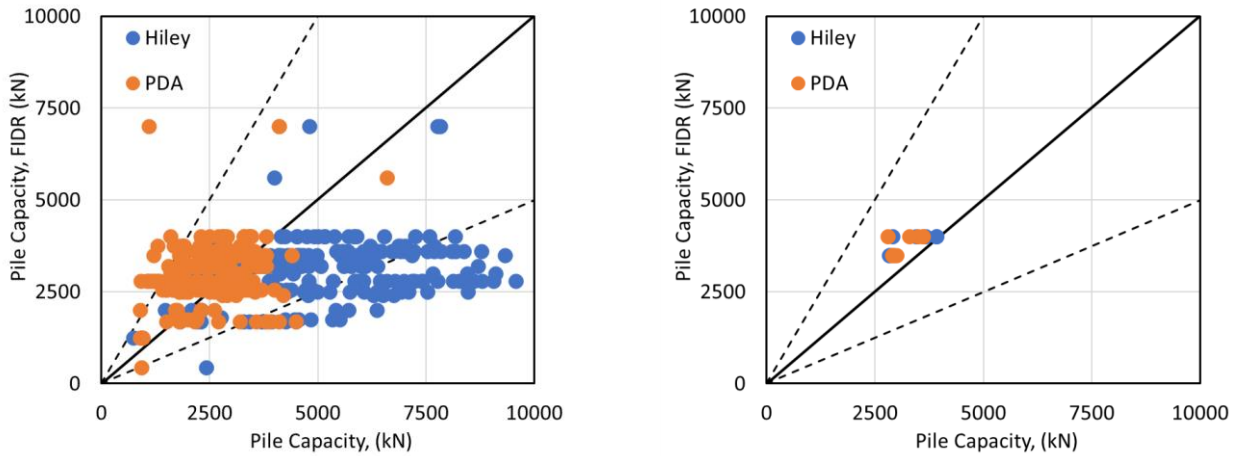
Drop hammers appear to perform accurately and reliably for both test methods, however caution should be used in interpreting this data as this may be due to the low sample size. The data collected from MTO and EXP sources were inadequate to draw meaningful conclusions about all types of hammers. Despite the data limitations, these findings were consistent with previous literature. In general, the Modified Hiley formula demonstrated good predictive ability for estimating pile capacity using drop hammers, similar to PDA, compared to diesel hammers. This finding is in agreement with Rauf and Rothenburg's (2011) study. It is worth mentioning that Rauf and Rothenburg's (2011) study found that the dataset for the Modified Hiley Formula showed greater variability and consistently lower coefficient of determination values when compared to the original formula. For hydraulic hammers, there were not enough data points to make the comparison in this study and Rauf and Rothenburg's (2011) study.

Table 36 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on hammer system

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	Diesel Hammers			
Number of Points	252			
Average	4792	2602	-62	12
Max	9571	6600	50	84
Min	745	900	-450	-165
Parameter	Drop Hammers			
Number of Points	9			
Average	3255	3167	14	16
Max	3919	3600	28	30
Min	2832	2800	2	10

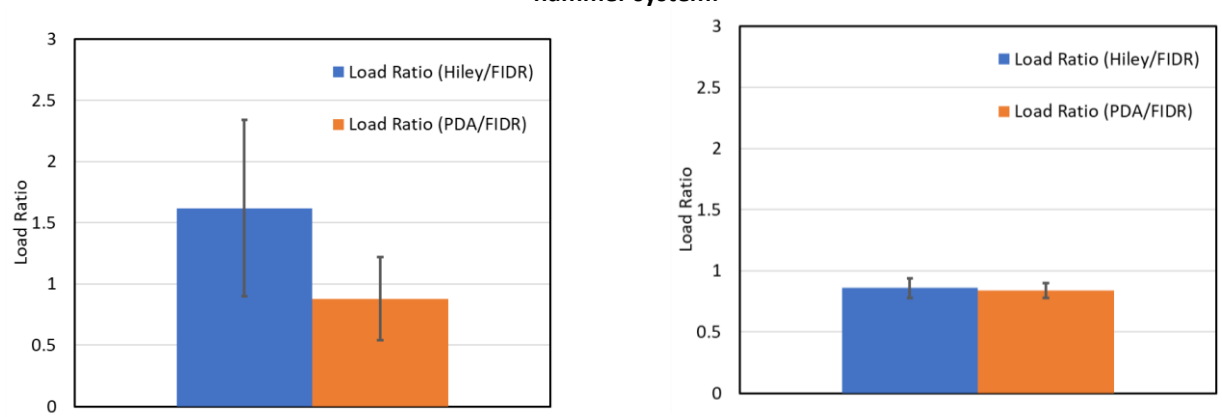
Table 37 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on hammer system

	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	Diesel Hammers		Drop Hammers	
No. of Points	252		9	
Average	1.62	0.88	0.86	0.84
Std Dev, σ	0.72	0.34	0.08	0.06
COV (%)	44	39	9	7
Max	5.5	2.65	0.98	0.9
Min	0.5	0.16	0.73	0.7



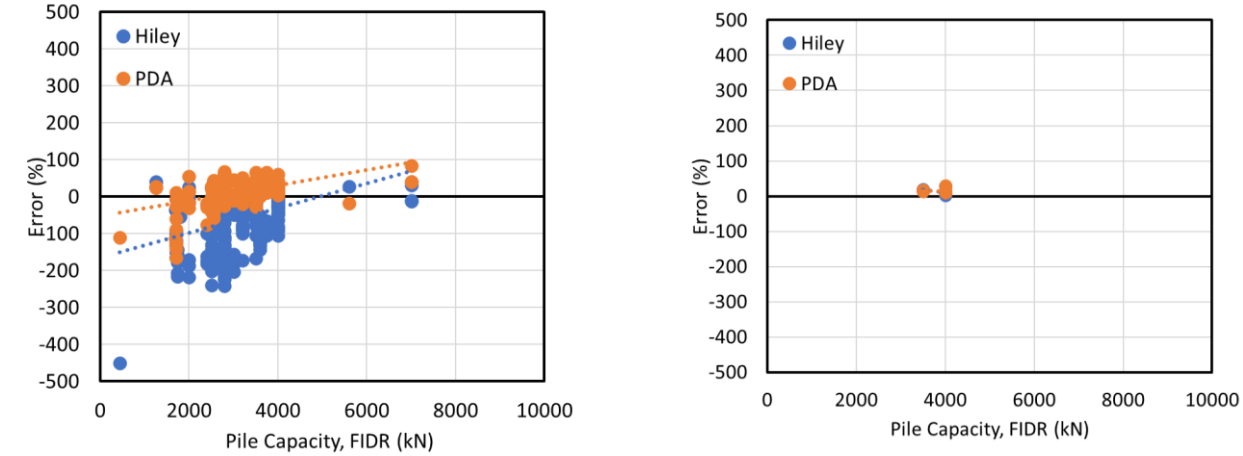
a) Diesel Hammers b) Drop Hammers

Figure 57 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on hammer system.



a) Diesel Hammers b) Drop Hammers

Figure 58 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on hammer system



a) Diesel Hammers b) Drop Hammers

Figure 59 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on hammer system

6.3.9 Pile Cushion

All steel H-Piles driven via diesel hammer analyzed in this study were driven without a cushion, while all piles driven via drop hammer were driven with a cushion. Therefore, no evaluation could be made of the effect of driving with a pile cushion on the PDA/Hiley resistance estimate. The graphs and statistical values generated for this parameter would be the same as the hammer system (Section 6.3.8).

6.3.10 Pile Shoe/Bearing Point

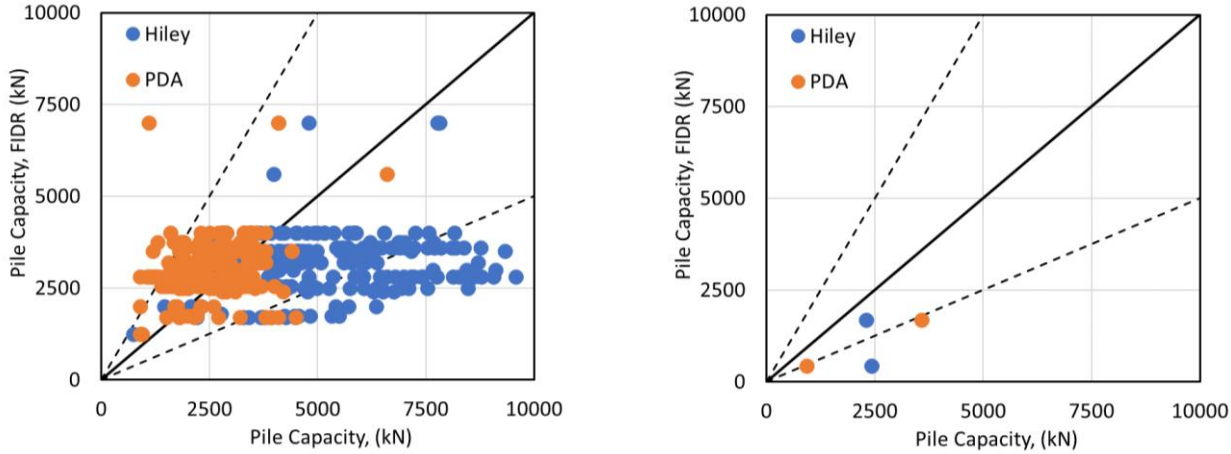
Figure 60 to Figure 62 shows the comparison between the estimated Hiley and PDA resistance and the FIDR ultimate resistance based on whether the pile was driven with a shoe/bearing point. Table 38 to Table 39 summarizes the statistical data. Only two piles were driven without a driving shoe/bearing point, therefore an evaluation could not be made on the effect of driving shoes on the estimated capacity from Hiley and PDA tests.

Table 38 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on pile shoe/bearing point

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	With Pile Shoe/Bearing Point			
Number of Points	262			
Average	4721	2613	-56	13
Max	9571	6600	50	84
Min	745	900	-242	-165
Parameter	Without Pile Shoe/Bearing Point			
Number of Points	2			
Average	2358	2251	-243	-111
Max	2420	3576	-36	-110
Min	2295	925	-450	-112

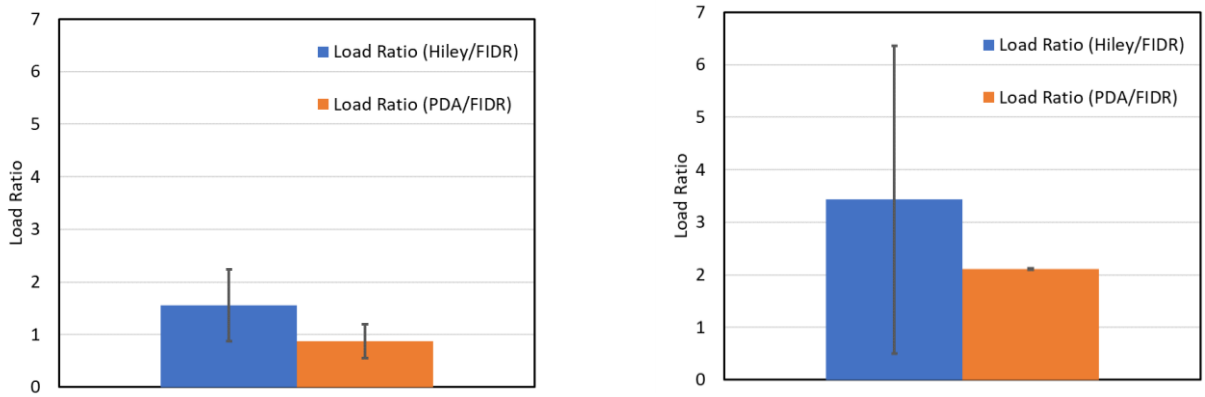
Table 39 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on pile shoe/bearing point

	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	With Pile Shoe/Bearing Point		Without Pile Shoe/Bearing Point	
No. of Points	262		2	
Average	1.56	0.87	3.43	2.11
Std Dev, σ	0.68	0.32	2.93	0.01
COV (%)	44	37	85	0
Max	3.42	2.65	5.5	2.12
Min	0.5	0.16	1.36	2.1



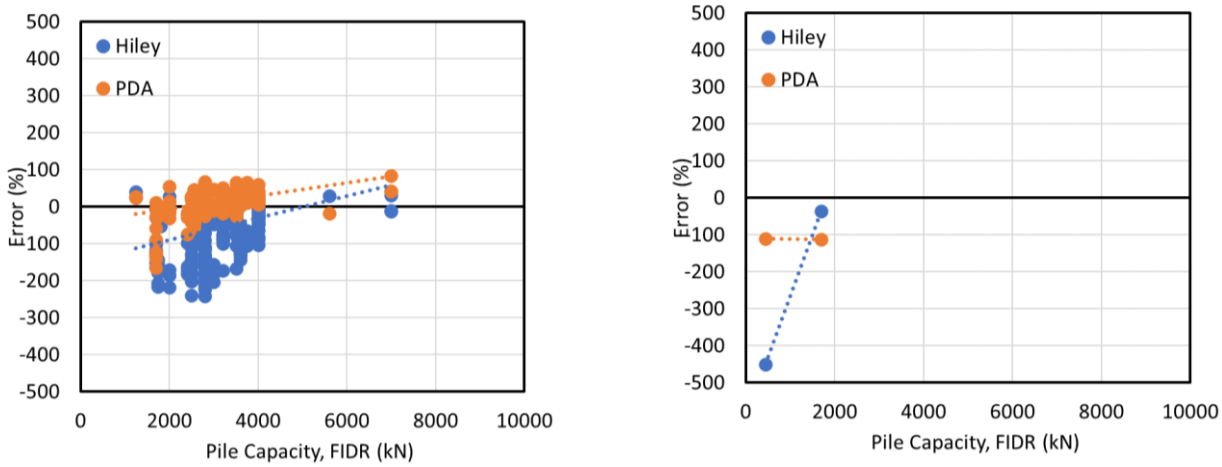
a) With Pile Shoe/Bearing Point b) Without Pile Shoe/Bearing Point

Figure 60 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on pile shoe/bearing point.



a) With Pile Shoe/Bearing Point b) Without Pile Shoe/Bearing Point

Figure 61 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on shoe/bearing point.



a) With Pile Shoe/Bearing Point b) Without Pile Shoe/Bearing Point

Figure 62 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on shoe/bearing point.

6.3.11 Hammer Rated Energy

Figure 63 shows a comparison between the estimated Hiley and PDA resistance and the FIDR ultimate resistance based on hammer rated energy. For hammers with a rated energy between 60 and 90 kJ and over 90 kJ, PDA tests show better distribution along the 1:1 line with the majority of data points occurring within the 1:2 and 2:1 line. Hiley test data points have a much greater amount of scatter with considerably more points landing below the 1:2 line indicating that Hiley tests overestimate the target ultimate resistance provided in FIDRs. For Hammers under 60 kJ, the Hiley test data points are better distributed along the 1:1 line compared to PDA tests. Table 40 shows a summary of the dataset of Hiley and PDA compared to the FIDR ultimate resistance based on hammer rated energy.

Figure 64 shows the average load ratio and standard deviation for the estimated Hiley and PDA resistance over the FIDR ultimate resistance. For PDA tests, the average load ratio was 0.8 with a COV of 43% for hammers under 60 kJ, 0.83 with a COV of 42% for hammers between 60 and 90 kJ, and 0.9 with a COV of 37% for hammers with a rated energy greater than 90 kJ. This suggests high energy hammers produce slightly more accurate and reliable results for PDA tests. For Hiley tests, the average load ratio was 1.15 with a COV of 85% for hammers under 60 kJ, 1.38 with a COV of 54% for hammers between 60 and 90 kJ, and 1.67 with a COV of 40% for hammers with a rated energy greater than 90 kJ. The accuracy of the Hiley test appears to decrease with increasing hammer energy, however the decreasing COV suggests that the values become more consistent with increased energy. Table 41 shows a summary of the statistical data concerning the load ratios.

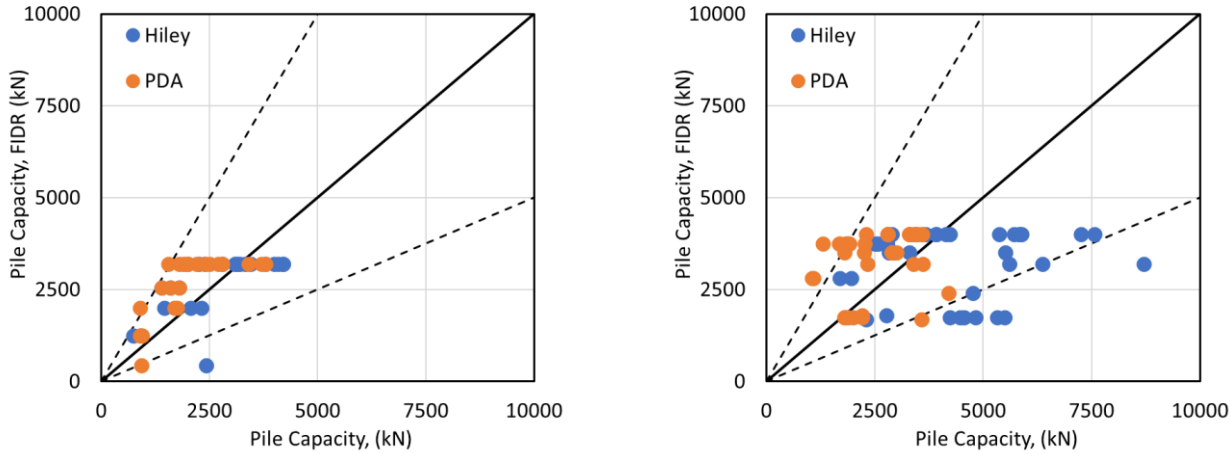
Figure 65 shows the distribution of percent-difference between the Hiley and PDA estimates and FIDR ultimate resistances, while Table 40 shows the min, max, and average values for both tests. For hammers with a rated energy between 60 and 90 kJ and over 90 kJ, the data points for PDA are much closer to the 0% line compared to Hiley tests, which tend to greatly overestimate the piles capacity. For Hammers under 60 kJ, the average percent difference for PDA tests and Hiley tests is similar. Removing the outlier points for Hiley tests, Hiley would appear to perform better than PDA tests, however taking all points into consideration, the comparison is similar.

Table 40 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on hammer rated energy

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	Energy, E ≤ 60 kJ			
Number of Points	23			
Average	2688	2027	-15	20
Max	4200	3800	45	55
Min	745	900	-450	-110
Parameter	Energy, 60 < E ≤ 90 kJ			
Number of Points	42			
Average	4124	2556	-38	17
Max	8700	4200	50	65
Min	1687	1050	-216	-112
Parameter	Energy, E > 90 kJ			
Number of Points	199			
Average	5058	2689	-67	10
Max	9571	6600	47	84
Min	1500	905	-242	-165

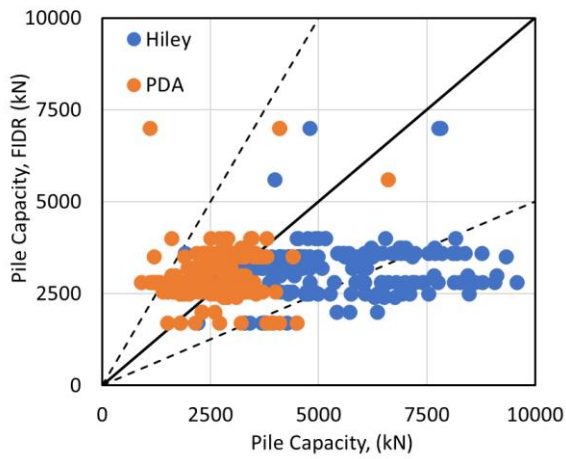
Table 41 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on hammer rated energy

	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	Energy, E ≤ 60 kJ		Energy, 60 < E ≤ 90 kJ		Energy, E > 90 kJ	
No. of Points	23		42		199	
Average	1.15	0.8	1.38	0.83	1.67	0.9
Std Dev, σ	0.98	0.34	0.75	0.35	0.66	0.33
COV (%)	85	43	54	42	40	37
Max	5.5	2.1	3.16	2.12	3.42	2.65
Min	0.55	0.45	0.5	0.35	0.53	0.16



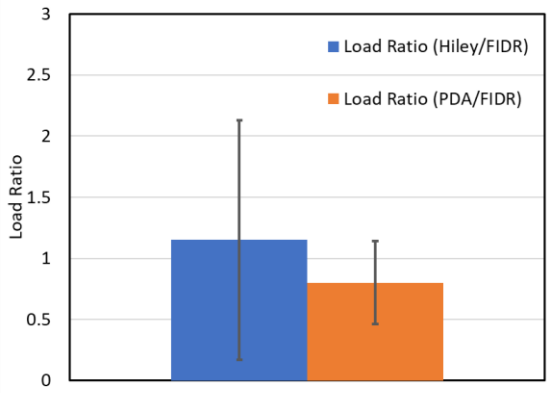
a) Energy, E ≤ 60 kJ

b) Energy, 60 < E ≤ 90 kJ

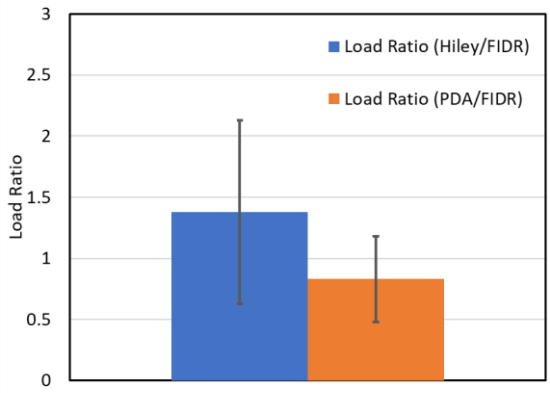


c) Energy, E > 90 kJ

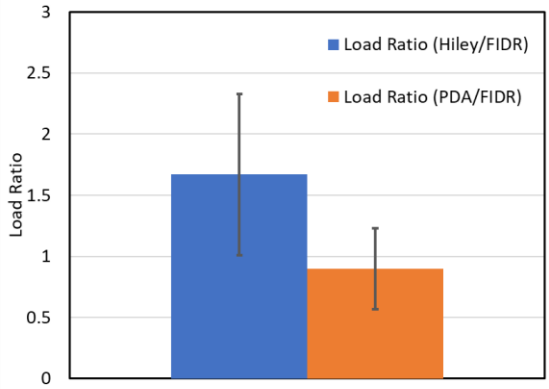
Figure 63 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on hammer rated energy



a) Energy, E ≤ 60 kJ

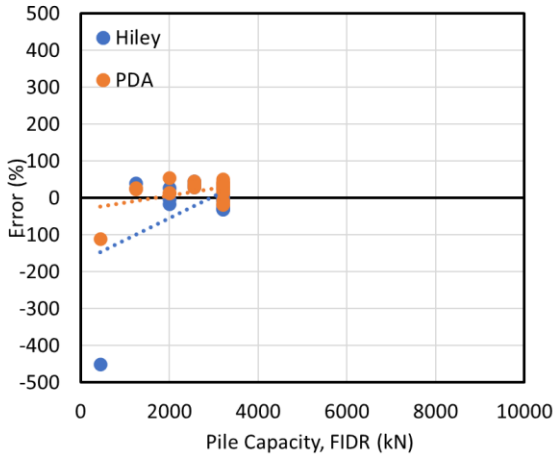


b) Energy, 60 < E ≤ 90 kJ

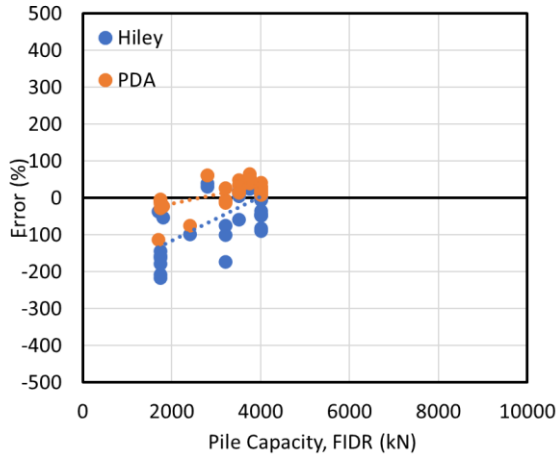


c) Energy, E > 90 kJ

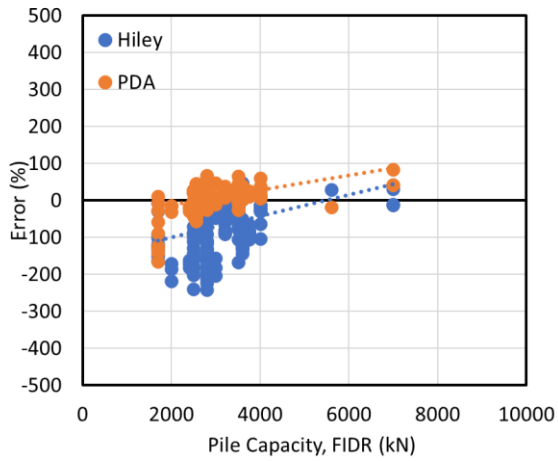
Figure 64 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on hammer rated energy



a) Energy, E ≤ 60 kJ



b) Energy, 60 < E ≤ 90 kJ



c) Energy, E > 90 kJ

Figure 65 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on hammer rated energy

6.3.12 Driving Resistance

Figure 66 shows a comparison between the estimated Hiley and PDA resistance and the FIDR ultimate resistance based on driving resistance. For the purpose of this study, low driving resistance is considered less than 2 blows per 25 mm, high driving resistance is considered 8 blows per 25 mm, and intermediate resistance is considered between and equal to these values. For high and intermediate resistances, PDA tests show better distribution along the 1:1 line with the majority of data points occurring within the 1:2 and 2:1 line. Hiley tests data points have a much greater amount of scatter with considerably more points landing below the 1:2 line indicating that Hiley tests overestimate the target ultimate resistance provided in FIDRs. For low driving resistance, Hiley tests show a good distribution along the 1:1 line while PDA tests align closer to the 2:1 line. However, we should consider that the data is limited to 7 points from 2 sites. Table 42 shows a summary of the dataset of Hiley and PDA compared to the FIDR ultimate resistance based on driving resistance.

Figure 67 shows the average load ratio and standard deviation for the estimated Hiley and PDA resistance over the FIDR ultimate resistance. For high driving resistance, PDA tests on average reach almost unity (0.97) while Hiley tests on average overestimate

the load by 44%. For intermediate driving resistance, PDA tests underestimate the FIDR ultimate resistance by a greater degree (17%) while Hiley tests overestimate the load to a greater degree (65%). For low driving resistance cases, Hiley tests had an average load ratio of 0.97, outperforming PDA tests which had an average load ratio of 0.56. This suggests that Hiley tests provide a good estimate while PDA tests estimate a value that is about half on average. Table 43 shows a summary of the statistical data concerning the load ratios.

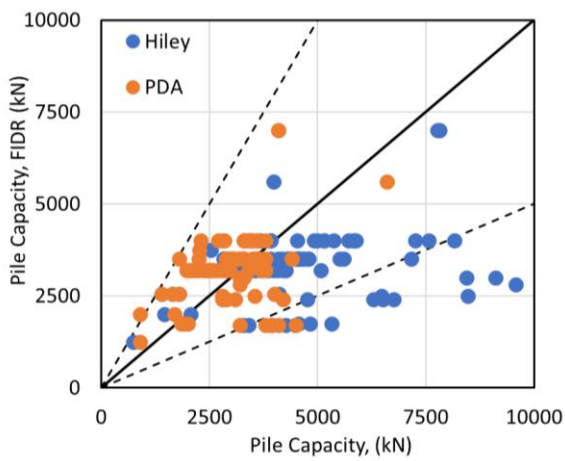
Figure 65 shows the distribution of percent-difference between the Hiley and PDA estimates and FIDR ultimate resistances, while Table 42 shows the min, max, and average values for both tests. The data points for PDA are much closer to the 0% line compared to Hiley for high and intermediate driving resistance data points. For low driving resistance cases, Hiley tests are closely aligned with the 0% line while PDA tests are distributed above it, indicating an underestimation when compared to the FIDR ultimate resistance.

Table 42 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on pile driving resistance

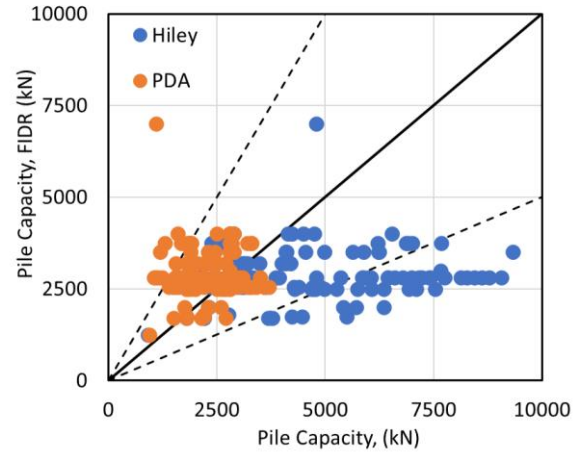
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	High Driving Resistance			
Number of Points	93			
Average	4488	3007	-44	3
Max	9571	6600	45	55
Min	745	900	-242	-165
Parameter	Intermediate Driving Resistance			
Number of Points	119			
Average	4629	2317	-65	17
Max	9327	3700	50	84
Min	919	950	-223	-59
Parameter	Low Driving Resistance			
Number of Points	7			
Average	2591	1507	5	44
Max	2828	2300	17	68
Min	2324	905	-3	10

Table 43 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on pile driving resistance

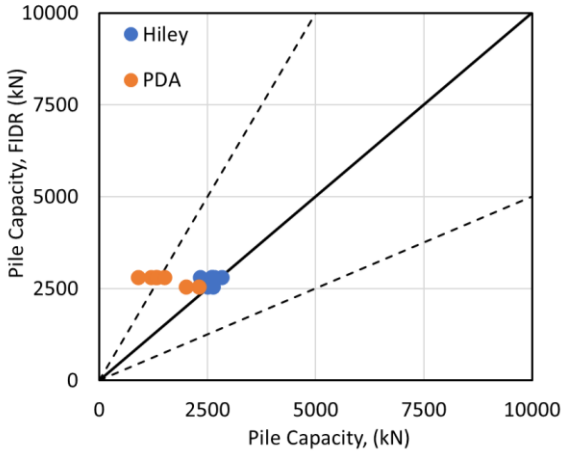
	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	High Driving Resistance		Intermediate Driving Resistance		Low Driving Resistance	
No. of Points	93		119		7	
Average	1.44	0.97	1.65	0.83	0.95	0.56
Std Dev, σ	0.68	0.4	0.76	0.28	0.34	0.27
COV (%)	47	41	46	34	36	48
Max	3.42	2.65	3.23	1.59	1.03	0.9
Min	0.55	0.45	0.5	0.16	0.83	0.32



a) High Driving Resistance

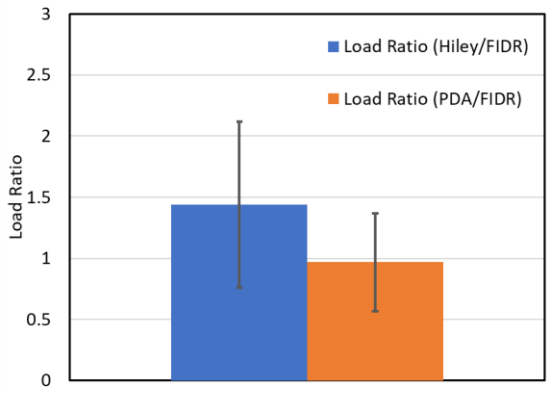


b) Intermediate Driving Resistance

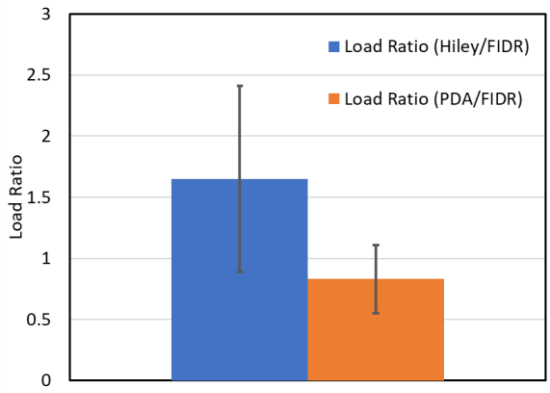


c) Low Driving Resistance

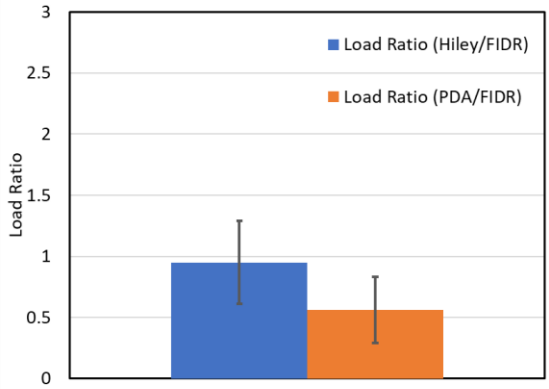
Figure 66 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on pile driving resistance



a) High Driving Resistance

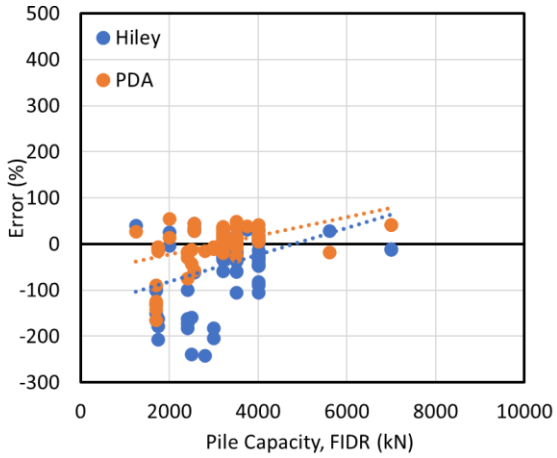


b) Intermediate Driving Resistance

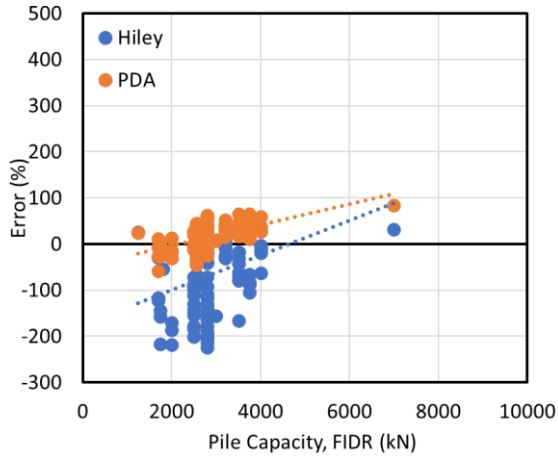


c) Low Driving Resistance

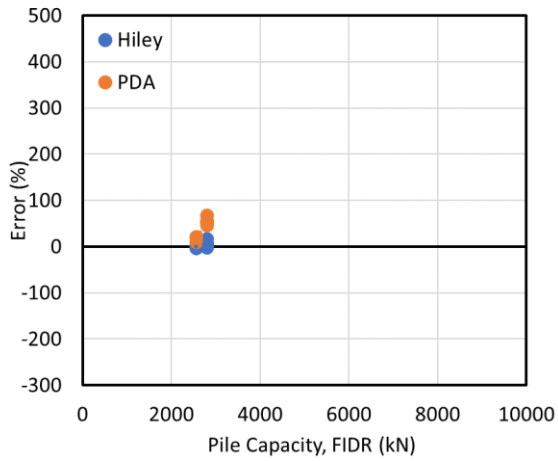
Figure 67 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on pile driving resistance



a) High Driving Resistance



b) Intermediate Driving Resistance



c) Low Driving Resistance

Figure 68 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on pile driving resistance

6.3.13 Diesel Hammer Specification

Figure 57 shows a comparison between the estimated Hiley and PDA resistance and the FIDR ultimate resistance based on diesel hammer specification, with only diesel hammers being considered as the other types lack a sufficient data set. For Berminghammer diesel hammers, PDA tests show a better distribution along the 1:1 line with the majority of data points occurring within the 2:1 line and 1:2 line. Hiley tests data points have a much greater amount of scatter with considerably more points landing below the 1:2 line indicating that Hiley tests overestimate the target ultimate resistance provided in FIDRs. For Delmag hammer, the data points are relatively equal in terms of distribution for both PDA and Hiley tests, landing within the 1:2 line and 2:1 line. For Pileco hammers, the data was collected from one site thus limiting the validity of data, but a lower scatter of data points was observed for PDA tests compared to Hiley tests. For APE hammers, more data points are needed to make a comparison. Table 44 shows a summary of the dataset of Hiley and PDA compared to the FIDR ultimate resistance based on diesel hammer specification.

Figure 58 and Table 45 show the average load ratio and variation in the data for the estimated Hiley and PDA resistance over the FIDR ultimate resistance. For Berminghammer, the load ratio is closer to unity for PDA tests, underestimating the FIDR ultimate resistance by 16% with a COV of 30%. Hiley tests overestimated the FIDR ultimate resistance by 73% with a COV of 42%. For Delmag hammer, the load ratio is closer to unity for PDA tests, underestimating the FIDR ultimate resistance by 12% with a COV of 52%. Also, the load ratio is closer to unity for Hiley tests. Hiley tests overestimated the FIDR ultimate resistance by 11% with a COV of 42%. For Pileco hammer, PDA tests overestimated the FIDR ultimate resistance by 31% with a COV of 43%. Hiley tests overestimated the FIDR ultimate resistance by 49% with a COV of 38%. For APE hammer, more data points are needed to make a comparison.

Figure 59 shows the distribution of percent-difference between the Hiley and PDA estimates and FIDR ultimate resistances, while Table 44 shows the min, max, and average values for both tests. For Berminghammer, PDA tests have a lower range of percent-difference with respect to FIDR ultimate resistance compared to Hiley tests, while the range of percent of difference was lower in case of Hiley tests compared to PDA for tests using a Delmag hammer. For Pileco hammers, while the range of percent of difference was approximately the same for both PDA and Hiley tests.

Table 44 - Summary of the dataset of Hiley and PDA compared to FIDR ULS resistances based on diesel hammer specification

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to FIDR ULS Capacity	% of Error-PDA to Static FIDR Capacity
Parameter	Berminghammer			
Number of Points	194			
Average	5307	2622	-73	16
Max	9571	4400	47	84
Min	1687	905	-450	-112
Parameter	Delmag			
Number of Points	39			
Average	2866	2217	-11	12
Max	4770	4200	50	65
Min	745	900	-132	-129
Parameter	Pileco			
Number of Points	18			
Average	3454	3003	-49	-31
Max	4888	4500	41	41
Min	1500	1500	-164	-165
Parameter	APE			
Number of Points	1			
Average	3989	6600	29	-18
Max	3989	6600	29	-18
Min	3989	6600	29	-18

Table 45 - Summary of the load ratio results of Hiley and PDA with respect to FIDR ULS resistances based on diesel hammer specification

	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)	Load Ratio (Hiley/FIDR)	Load Ratio (PDA/FIDR)
Parameter	Berminghammer		Delmag	
No. of Points	194		39	
Average	1.73	0.84	1.11	0.88
Std Dev, σ	0.73	0.25	0.47	0.46
COV (%)	42	30	42	52
Max	5.5	2.12	2.32	2.29
Min	0.53	0.16	0.5	0.35
Parameter	Pileco		APE	
No. of Points	18		1	
Average	1.49	1.31	0.71	1.18
Std Dev, σ	0.56	0.56	---	---
COV (%)	38	43	---	---
Max	2.64	2.65	0.71	1.18
Min	0.59	0.59	0.71	1.18

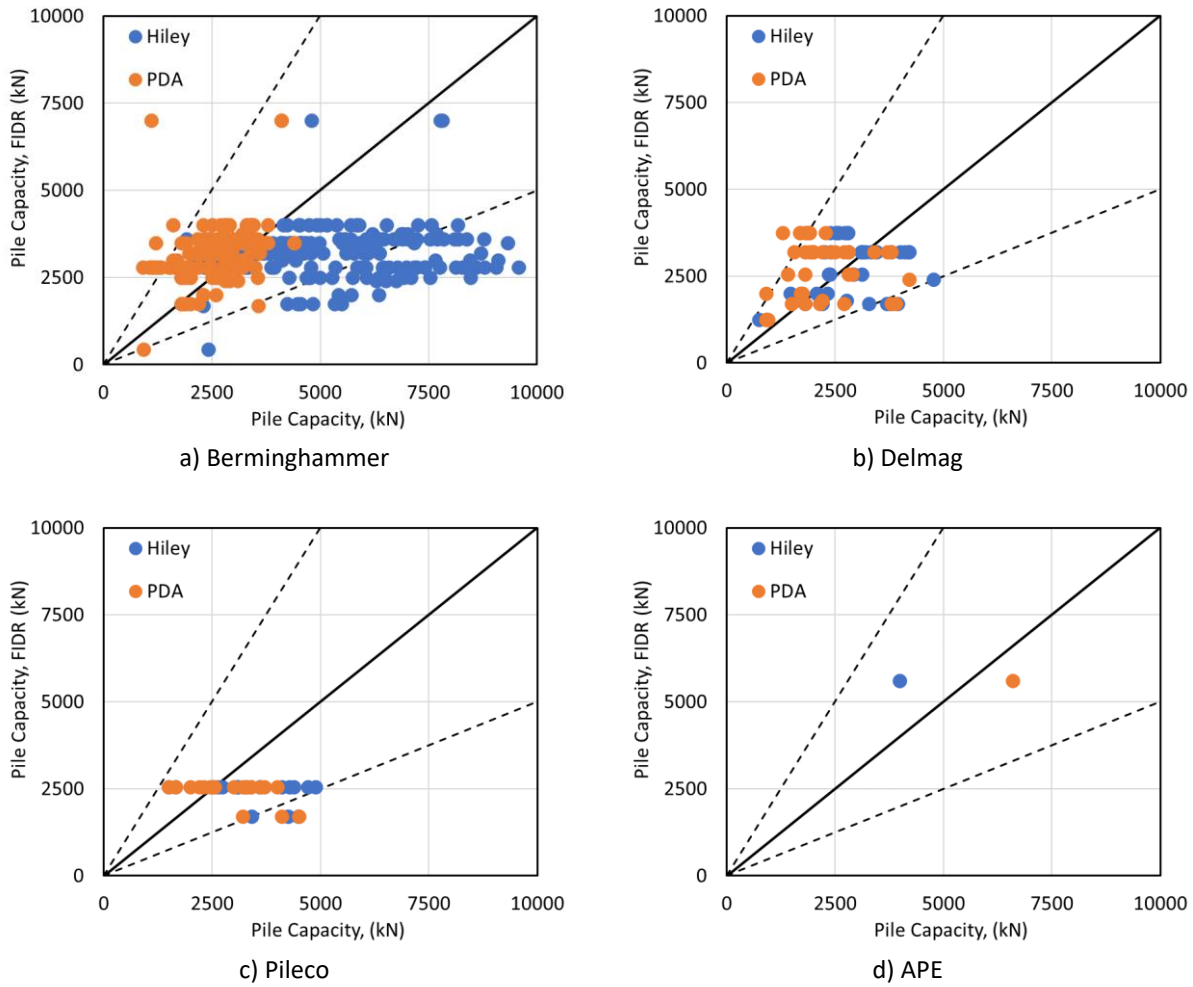
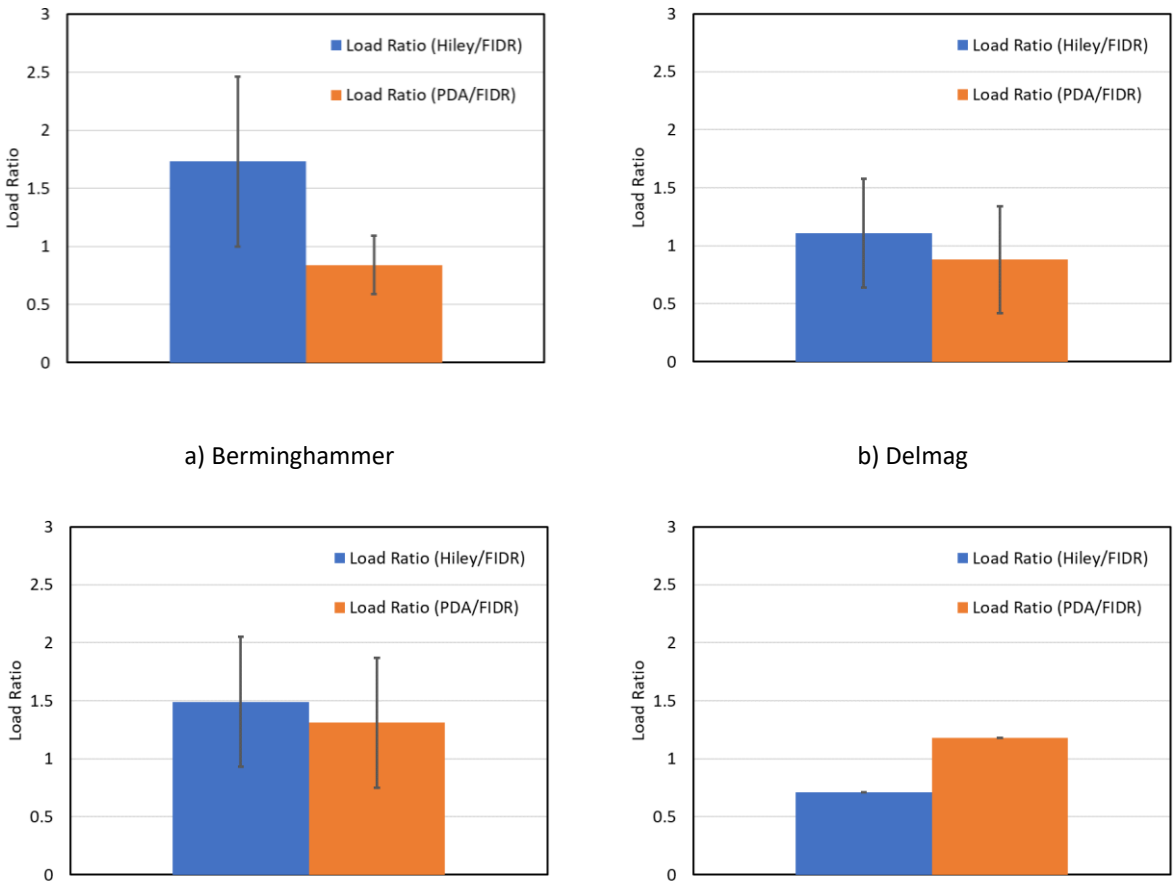


Figure 69 - Comparison between the estimated pile capacities of Hiley and PDA with respect to the FIDR ULS load based on diesel hammer specification



a) Berminghammer

b) Delmag

c) Pileco

d) APE

Figure 70 - Comparison between Hiley and PDA Load ratio with respect to the FIDR ULS load based on diesel hammer speciation

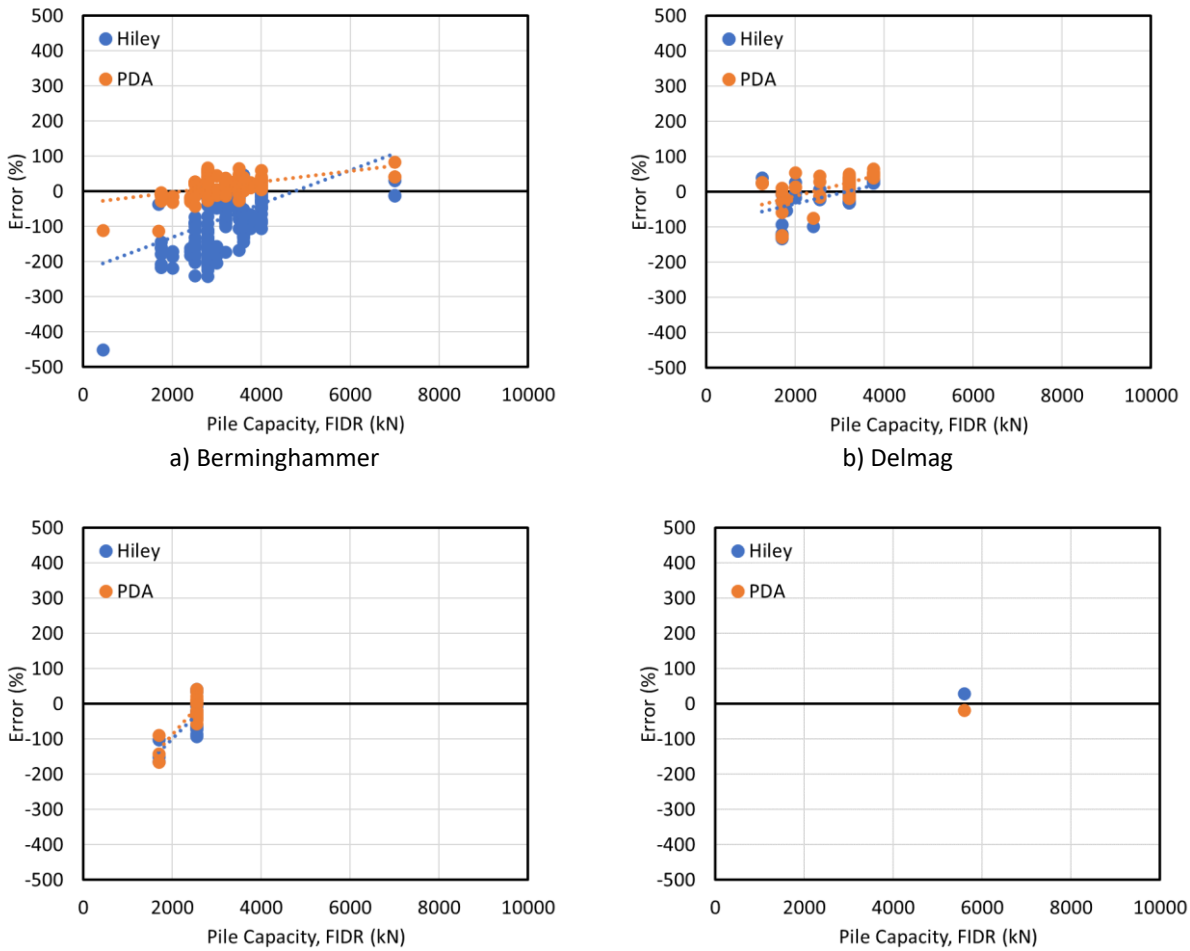


Figure 71 - Comparison between the percentage of error of the capacities of Hiley and PDA with respect to the FIDR ULS load based on diesel hammer specification

6.4 Hiley vs. PDA

6.4.1 All Data

Figure 72 shows the relationship between the capacities obtained from Hiley tests to PDA tests based on all data considered simultaneously. Figure 72 shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 of 0.26 and considerably more data points landing near the 1:2 line indicating Hiley tests estimate a higher load than Hiley tests. It is also observed that as the pile resistance increases, the relative amount by which Hiley tests overestimates the PDA test value increases. Table 46 shows a summary of the dataset of Hiley and PDA tests based on all data.

Figure 73 and Table 47 show the load ratio of Hiley to PDA results. Figure 73 and Table 47 show that the results of Hiley tests on average estimate a load that is 83% higher than PDA with a COV of 38% in the datapoints indicating relatively high levels of scatter. Table 47 shows a summary of Hiley to PDA statistical results based on all data.

Figure 74 and Table 46 shows the wide range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on all data.

Table 46 - Summary of the comparison between the capacities from Hiley and PDA based on all data

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Number of Points	284		
Average	4526	2533	-83
Max	9571	6600	48
Min	745	600	-419
R^2	0.26	---	---

Table 47 - Summary of the load ratio results of Hiley to PDA based on all data

	Load Ratio (Hiley/Static)
Average	284
Standard Deviation, σ	1.83
Coefficient of Variation, COV (%)	0.69
Max	38
Min	5.19
Average	0.52

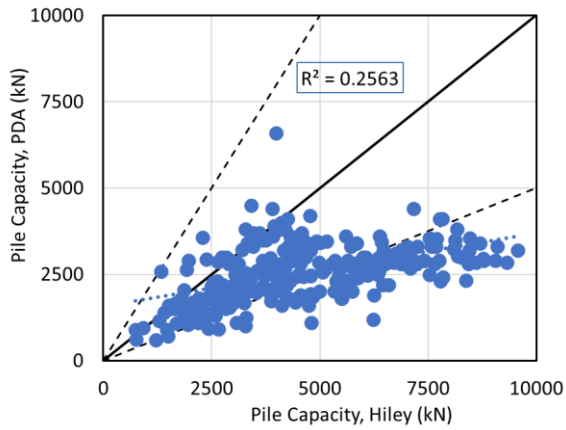


Figure 72 - PDA, pile capacity vs. Hiley, pile capacity based on all data

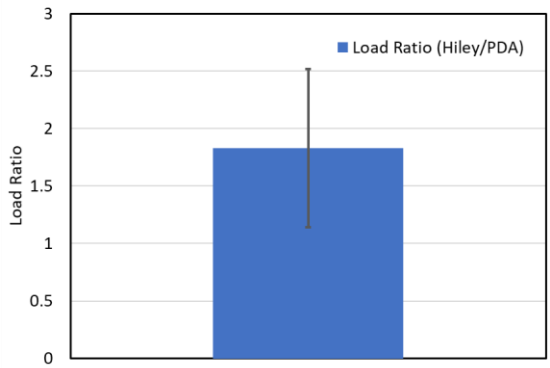


Figure 73 - Hiley to PDA Load ratio based on all data

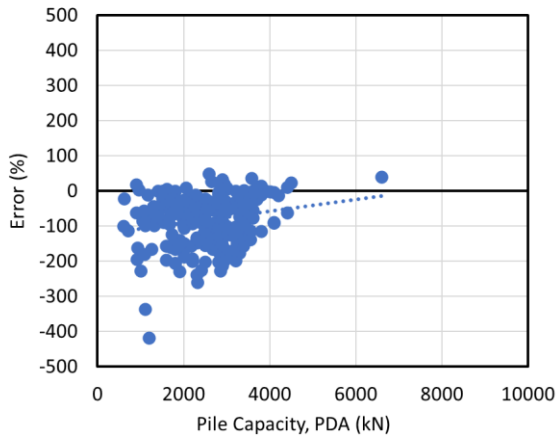


Figure 74 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on all data

6.4.2 Subsurface Condition and Load Transfer Mechanism

Figure 75 shows that there is poor agreement between Hiley tests and PDA tests for all subsurface conditions and load transfer mechanisms analyzed, with a low R^2 value and considerably all data points landing near the 1:2 line indicating that Hiley tests consistently provide much higher estimates of the pile resistance compared to PDA testing. There is a much lower correlation between the two testing methods for piles seated on bedrock, while for the other methods, while scattered, show a clearer trend. Table 48 shows a summary of the dataset of Hiley and PDA tests based on the subsurface condition and load transfer mechanism.

Figure 76 and Table 49 show the load ratio of Hiley to PDA results based on the subsurface condition and load transfer mechanism. For end bearing piles driven into bedrock, Figure 76a and Table 49 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 155% with a COV of 46%. For end bearing and friction piles driven into cohesive and cohesionless soils, Figure 76b to Figure 76f and Table 49 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 68% to 91% with a COV ranging from 26% to 37%. Table 49 shows a summary of Hiley to PDA statistical results based on the subsurface condition and load transfer mechanism.

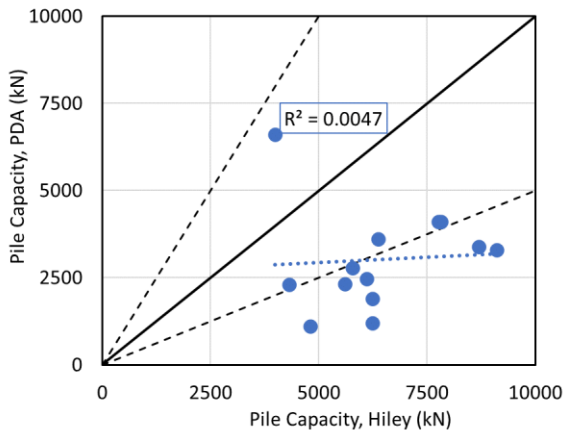
Figure 77 and Table 48 show a wide range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on the subsurface condition and load transfer mechanism. The data points are consistently below the 0% line for all cases indicating that Hiley tests provide a much higher estimate of a pile's resistance compared to PDA tests.

Table 48 - Summary of the comparison between the capacities from Hiley and PDA based on the subsurface condition and load transfer mechanism

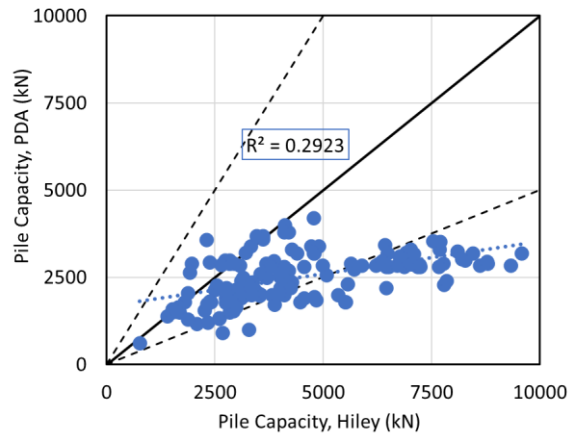
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	End Bearing Piles – Bedrock		
Number of Points	13		
Average	6372	3013	-155
Max	9105	6600	40
Min	3989	1100	-419
R^2	0		---
Parameter	End Bearing Piles – Cohesionless		
Number of Points	143		
Average	4442	2498	-79
Max	9571	4200	36
Min	756	623	-238
R^2	0.29		---
Parameter	End Bearing Piles – Cohesive		
Number of Points	69		
Average	5035	2682	-91
Max	9057	4400	11
Min	2345	1400	-212
R^2	0.15		---
Parameter	Friction Piles – Layered		
Number of Points	35		
Average	4154	2606	-68
Max	7845	4500	48
Min	1334	925	-226
R^2	0.1		---
Parameter	Friction Piles – Cohesionless		
Number of Points	22		
Average	2913	1736	-71
Max	5881	2850	6
Min	1290	1050	-180
R^2	0.66		---
Parameter	Friction Piles – Cohesive		
Number of Points	45		
Average	4157	2379	-77
Max	8376	4400	17
Min	745	600	-261
R^2	0.46		---

Table 49 -Summary of the load ratio results of Hiley to PDA based on the subsurface condition and load transfer mechanism

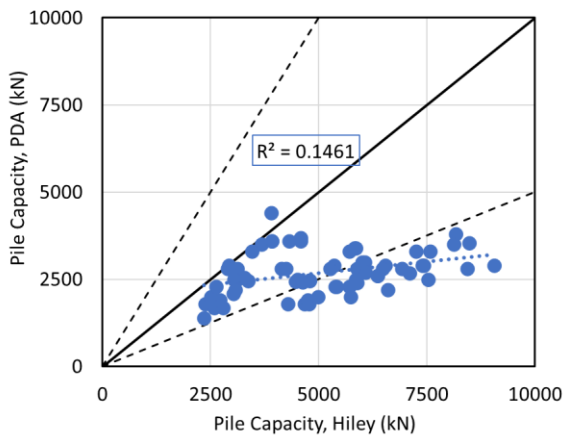
	Load Ratio (Hiley/Static)		
Parameter	End Bearing Piles – Bedrock	End Bearing Piles – Cohesionless	End Bearing Piles – Cohesive
No. of Points	13	143	69
Average	2.55	1.79	1.91
Std Dev, σ	1.18	0.66	0.6
COV (%)	46	37	31
Max	5.19	3.38	3.12
Min	0.6	0.64	0.89
Parameter	Friction Piles – Layered	Friction Piles – Cohesionless	Friction Piles – Cohesive
No. of Points	35	22	45
Average	1.68	1.71	1.77
Std Dev, σ	0.62	0.45	0.56
COV (%)	37	26	32
Max	3.26	2.8	3.61
Min	0.52	0.94	0.83



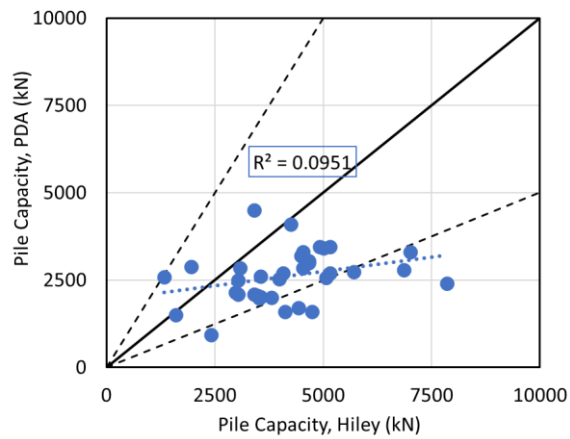
a) End Bearing Piles – Bedrock



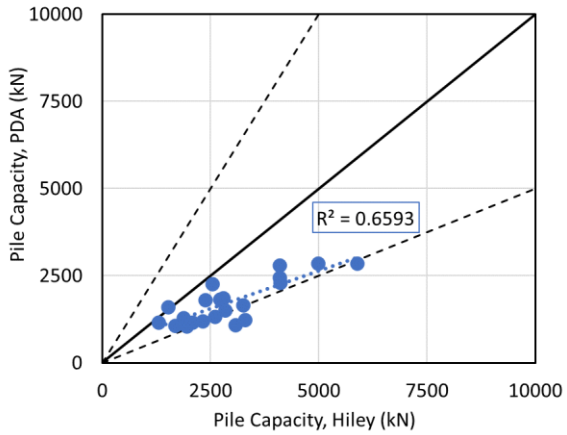
b) End Bearing Piles – Cohesionless



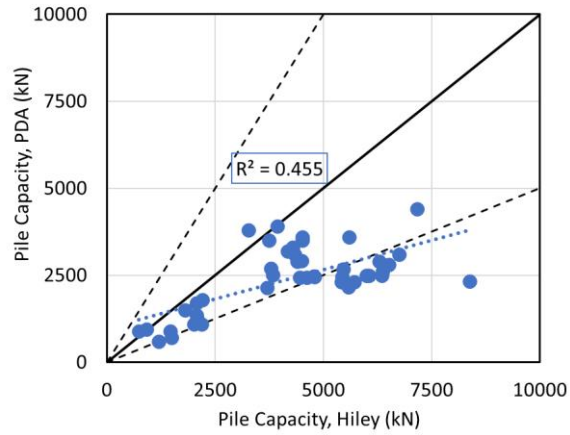
b) End Bearing Piles – Cohesive



d) Friction Piles – Layered

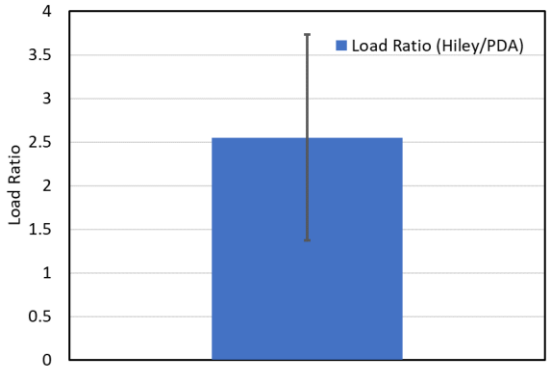


a) Friction Piles – Cohesionless

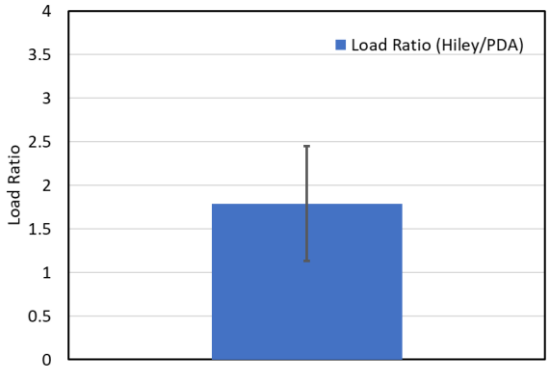


f) Friction Piles – Cohesive

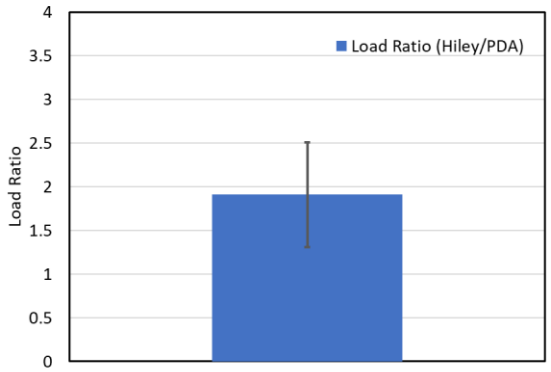
Figure 75 - PDA, pile capacity vs. Hiley, pile capacity based on the subsurface condition and load transfer mechanism



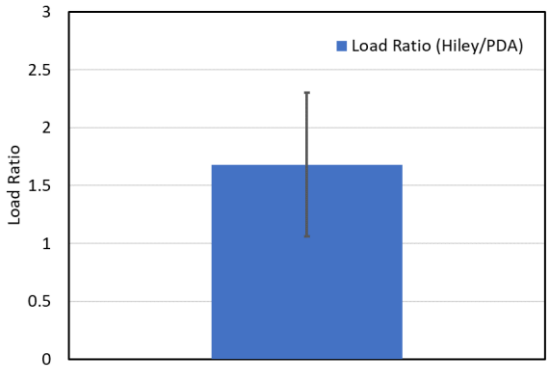
a) End Bearing Piles – Bedrock



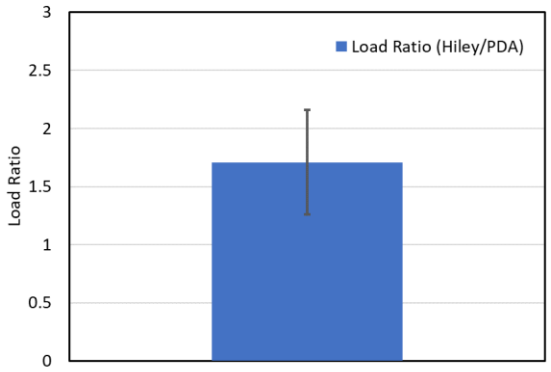
b) End Bearing Piles – Cohesionless



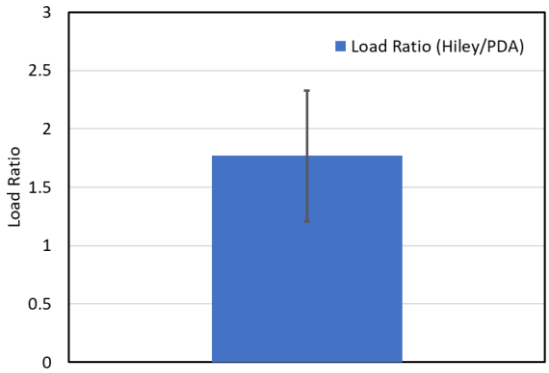
c) End Bearing Piles – Cohesive



d) Friction Piles – Layered

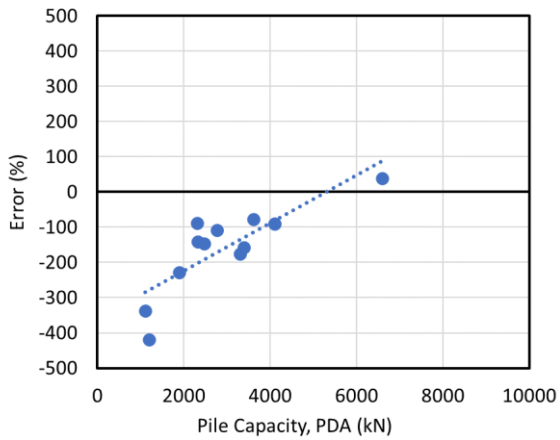


e) Friction Piles – Cohesionless

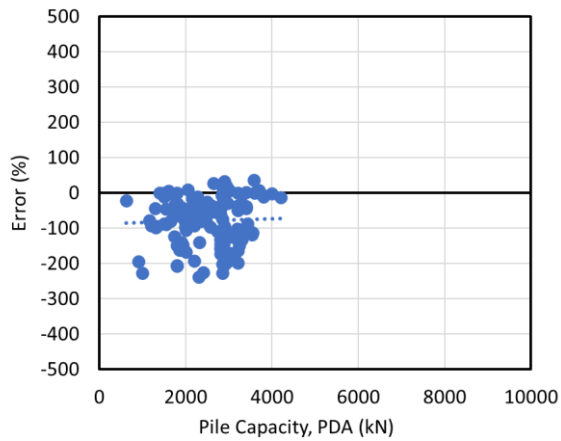


f) Friction Piles – Cohesive

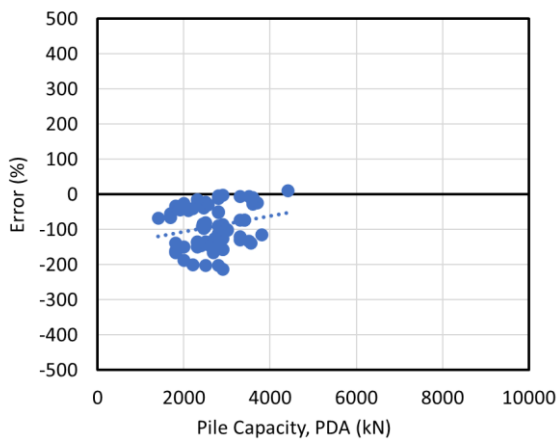
Figure 76 - Hiley to PDA Load ratio based on the subsurface condition and load transfer mechanism



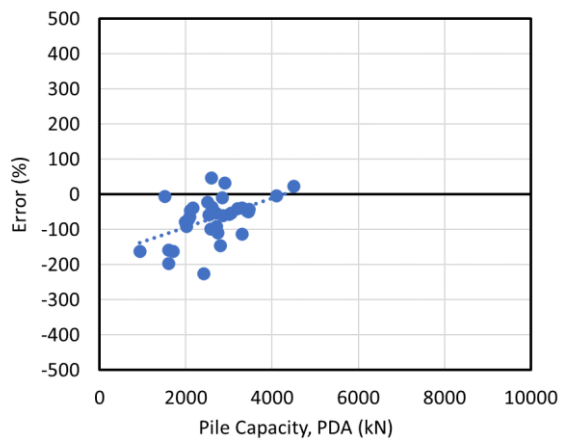
a) End Bearing Piles – Bedrock



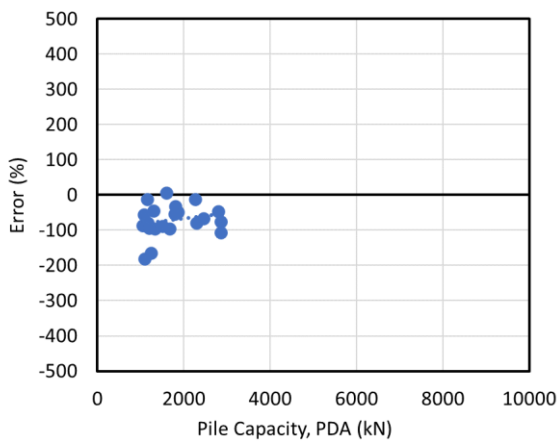
b) End Bearing Piles – Cohesionless



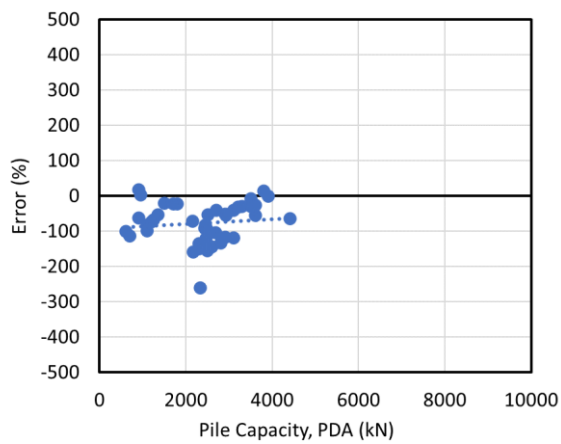
c) End Bearing Piles – Cohesive



d) Friction Piles – Layered



e) Friction Piles – Cohesionless



f) Friction Piles – Cohesive

Figure 77 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on the subsurface condition and load transfer mechanism

6.4.3 Pile Inclination

Figure 78 shows the relation between the capacities obtained from Hiley tests to PDA tests based on pile inclination. For vertical piles, Figure 78a show that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.27 and considerably more data points landing near the 1:2 line. For battered piles, Figure 78b shows a very similar distribution of points which indicates poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.29 and considerably more data points landing near the 1:2 line. Table 50 shows a summary of the dataset of Hiley and PDA tests based on pile inclination.

Figure 79 and Table 51 show the load ratio of Hiley to PDA results. For vertical piles, Figure 79a and Table 51 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 87% with a COV of 37%. For battered piles, Figure 79b and Table 51 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 66% with a COV of 38%. Table 51 shows a summary of Hiley to PDA statistical results based on pile inclination.

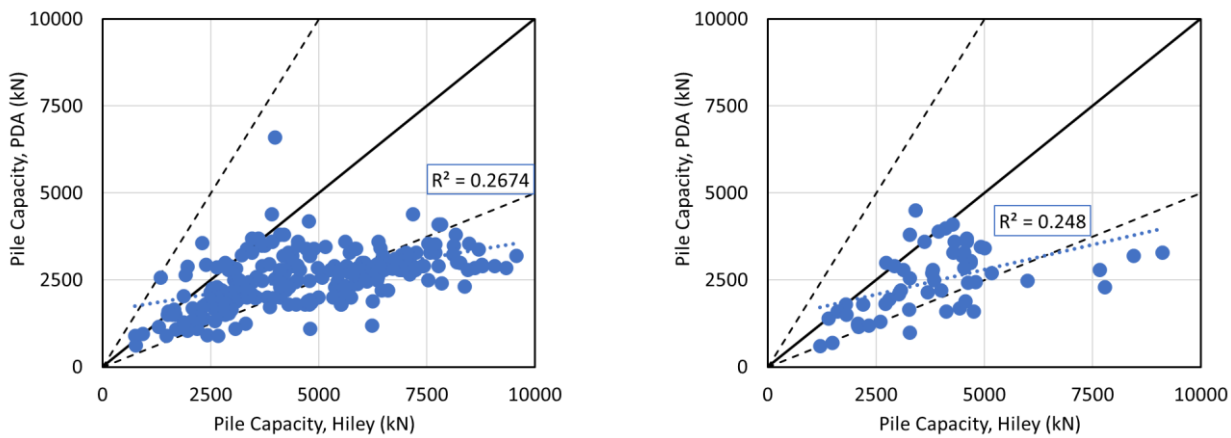
Figure 80 and Table 50 shows a wide range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on pile inclination.

Table 50 - Summary of the comparison between the capacities from Hiley and PDA based on pile inclination

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	Vertical Piles		
Number of Points	228		
Average	4688	2546	-87
Max	9571	6600	48
Min	745	623	-419
R^2	0.27		---
Parameter	Battered piles		
Number of Points	56		
Average	3866	2477	-66
Max	9105	4500	24
Min	1204	600	-238
R^2	0.25		---

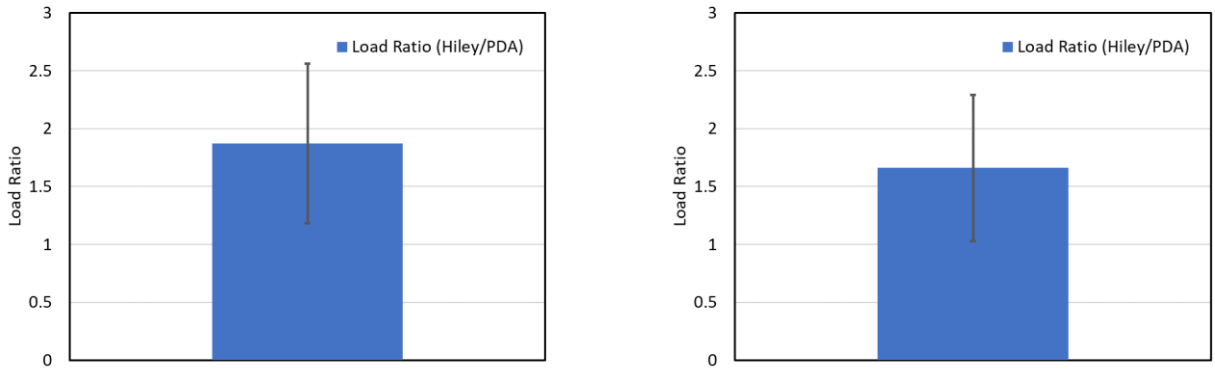
Table 51 - Summary of the load ratio results of Hiley to PDA based on pile inclination

	Load Ratio (Hiley/Static)	
Parameter	Vertical Piles	Battered piles
No. of Points	228	56
Average	1.87	1.66
Std Dev, σ	0.69	0.63
COV (%)	37	38
Max	5.19	3.38
Min	0.52	0.76



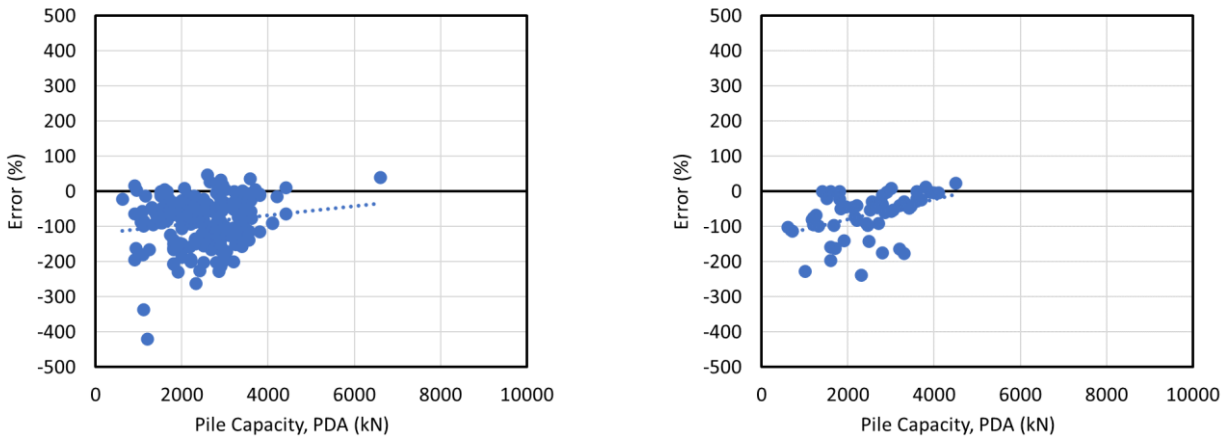
a) Vertical Piles b) Battered piles

Figure 78 - PDA, pile capacity vs. Hiley, pile capacity based on pile inclination



a) Vertical Piles b) Battered piles

Figure 79 - Hiley to PDA Load ratio based on pile inclination



a) Vertical Piles b) Battered piles

Figure 80 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on pile inclination

6.4.4 Pile Type

Figure 81 shows the relationship between the capacities obtained from Hiley tests to PDA tests based on pile type. For H-piles, Figure 81a show that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.25 and considerably more data points landing near the 1:2 line. For pipe piles, Figure 81b shows that there is relatively good agreement between Hiley tests and PDA tests, with an R^2 value of 0.94. For precast piles, Figure 81c shows there is relatively good agreement between Hiley tests and PDA tests, with an R^2 of 0.9; however, no conclusion can be made based on 3 points. For timber piles (Figure 81c), no conclusion can be made based on 2 points. Table 52 shows a summary of the dataset of Hiley and PDA tests based on pile type.

Figure 82 show the load ratio of Hiley to PDA results. For H-piles, Figure 82a and Table 53 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 86% with a COV of 37%. For pipe piles, Figure 82b and Table 53 show that the results of Hiley tests on underestimated the geotechnical capacity obtained from PDA tests by 20% with a COV of 24%. For precast concrete piles and timber piles (Figure 82c and Figure 82d), no conclusion can be made due to the limited number of points.

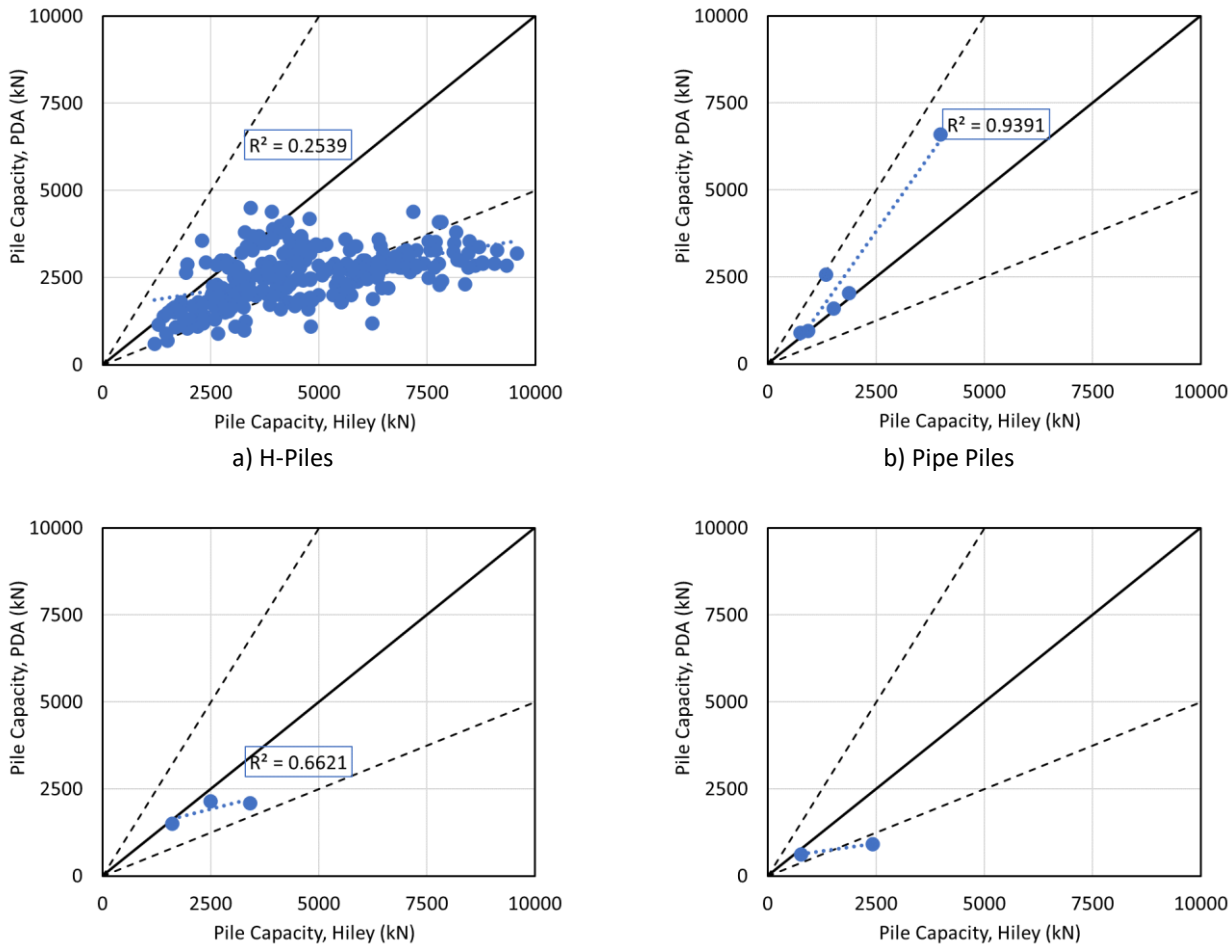
Figure 83 and Table 52 show the range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on pile type.

Table 52 - Summary of the comparison between the capacities from Hiley and PDA based on pile type

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	H - Piles		
Number of Points	273		
Average	4631	2554	-86
Max	9571	4500	36
Min	1204	600	-419
R^2	0.25		---
Parameter	Pipe Piles		
Number of Points	6		
Average	1728	2446	20
Max	3989	6600	48
Min	745	900	3
R^2	0.94		---
Parameter	Precast Concrete Piles		
Number of Points	3		
Average	2500	1919	-28
Max	3407	2153	-6
Min	1601	1512	-63
R^2	0.66		---
Parameter	Timber Piles		
Number of Points	2		
Average	1588	774	-91
Max	2420	925	-21
Min	756	623	-162
R^2	---		---

Table 53 - Summary of the load ratio results of Hiley to PDA based on pile type

	Load Ratio (Hiley/Static)			
Parameter	H-Piles	Pipe Piles	Precast Concrete Piles	Timber Piles
No. of Points	273	6	3	2
Average	1.86	0.8	1.28	1.92
Std Dev, σ	0.68	0.19	0.3	1
COV (%)	37	24	23	52
Max	5.19	0.97	1.63	2.62
Min	0.64	0.52	1.06	1.21



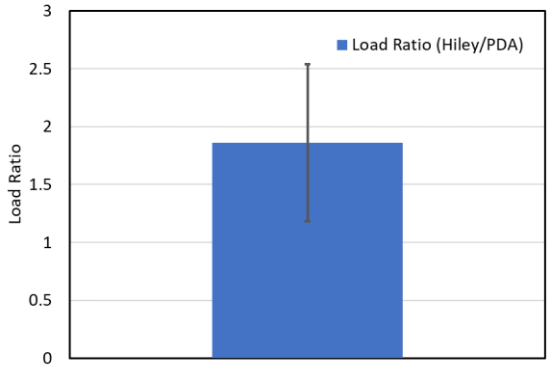
a) H-Piles

b) Pipe Piles

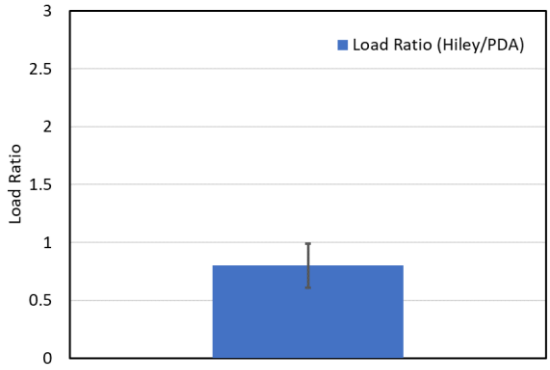
c) Precast Concrete Piles

d) Timber Piles

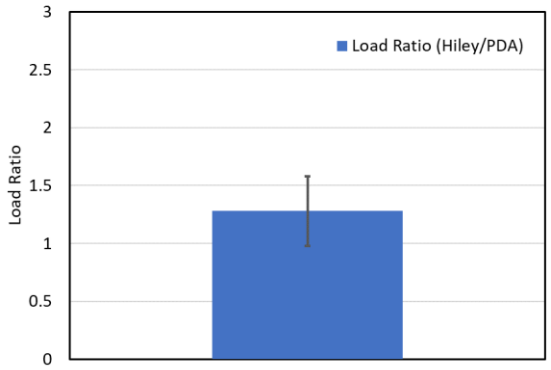
Figure 81 - PDA, pile capacity vs. Hiley, pile capacity based on pile type



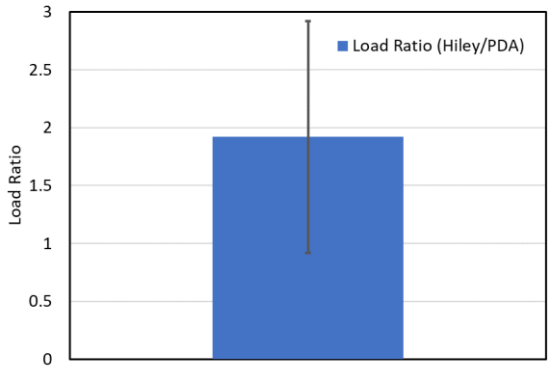
a) H-Piles



b) Pipe Piles



c) Precast Concrete Piles



d) Timber Piles

Figure 82 - Hiley to PDA Load ratio based on pile type

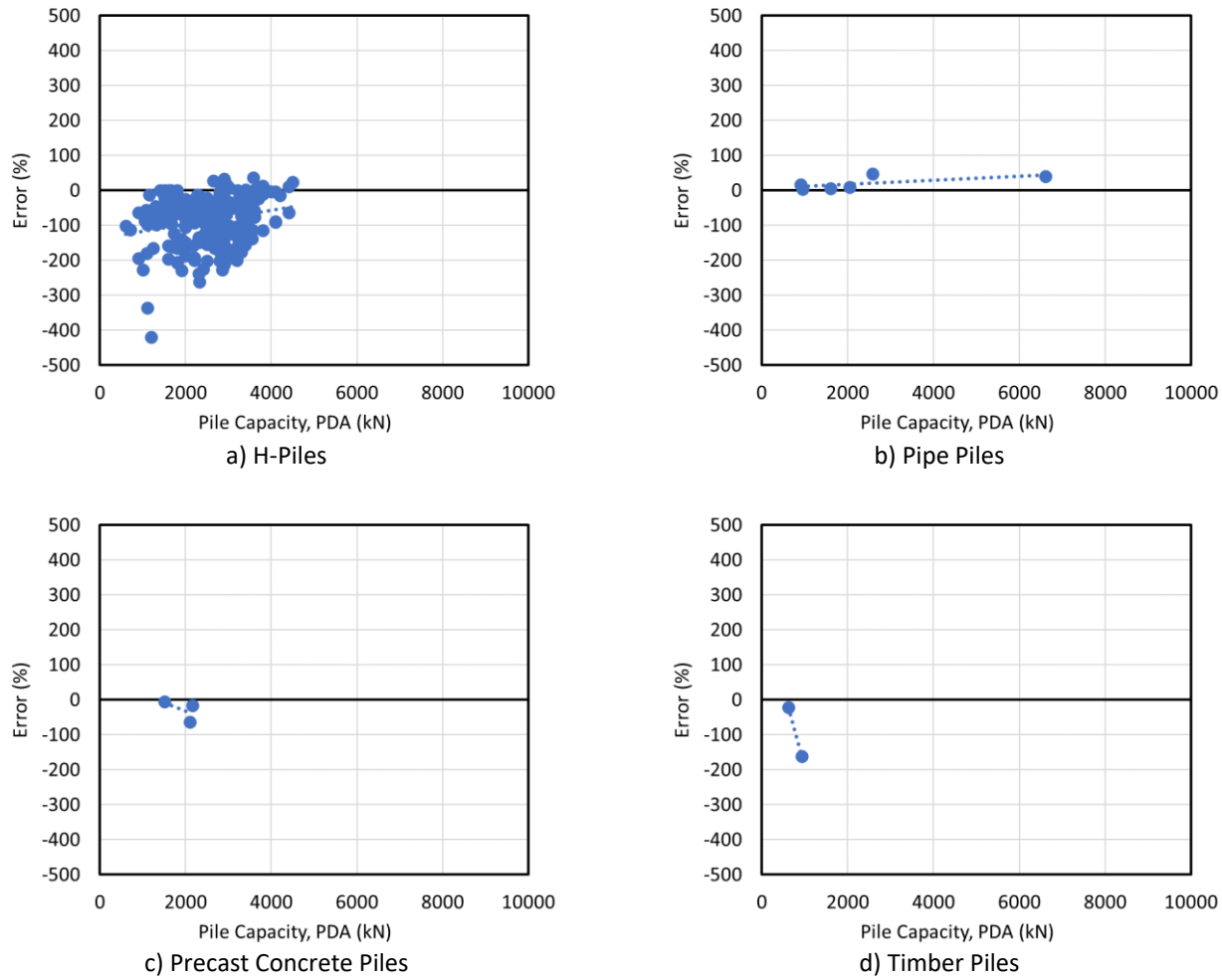


Figure 83 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on pile type

6.4.5 H-Pile Size

Figure 84 shows the relationship between the capacities obtained from Hiley tests to PDA tests based on H-pile sizes. Figure 84a to Figure 84d show that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value and most points landing near the 1:2 line for all cases. Table 54 shows a summary of the dataset of Hiley and PDA tests based on H-pile size.

Figure 85 and Table 55 show the load ratio of Hiley to PDA results based on H-pile sizes. Figure 85a to Figure 85d and Table 55 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 71% to 131%. Table 55 shows a summary of Hiley to PDA statistical results based on H-pile size.

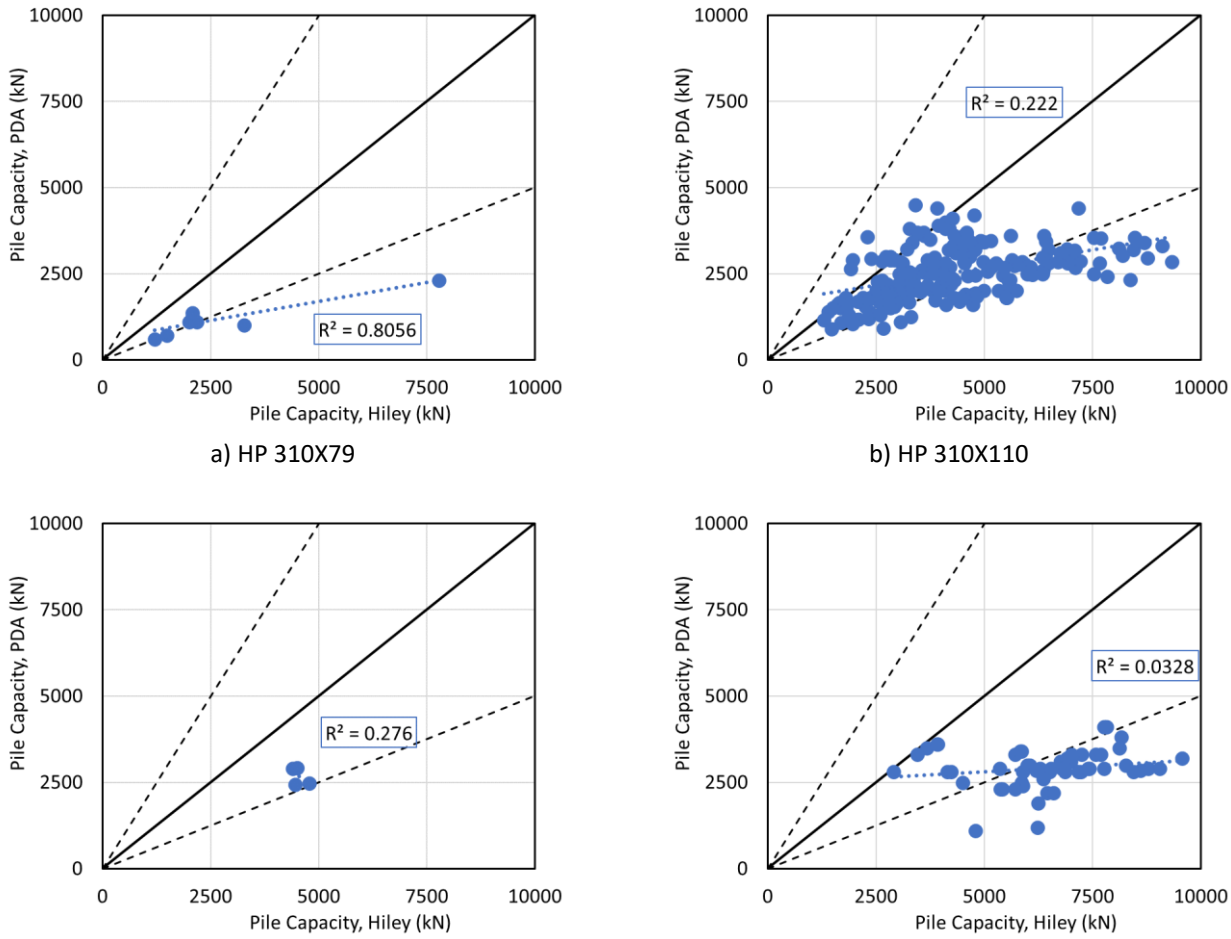
Figure 86 and Table 54 show a wide range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on the H-pile size.

Table 54 - Summary of the comparison between the capacities from Hiley and PDA based on H-pile size

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	HP 310X79		
Number of Points	9		
Average	2687	1178	-117
Max	7784	2300	-54
Min	1204	600	-238
R^2	0.81		--
Parameter	HP 310X110		
Number of Points	205		
Average	4235	2518	-73
Max	9327	4500	36
Min	1290	900	-261
R^2	0.22		--
Parameter	HP 310X132		
Number of Points	4		
Average	4535	2685	-70
Max	4787	2920	-52
Min	4401	2440	-93
R^2	0.28		--
Parameter	HP 310X174		
Number of Points	55		
Average	6432	2904	-131
Max	9571	4100	-4
Min	2900	1100	-419
R^2	0.03		--

Table 55 - Summary of the load ratio results of Hiley to PDA based on H-pile size

	Load Ratio (Hiley/Static)			
Parameter	HP 310X79	HP 310X110	HP 310X132	HP 310X174
No. of Points	9	205	4	55
Average	2.17	1.73	1.71	2.31
Std Dev, σ	0.68	0.61	0.21	0.73
COV (%)	31	35	12	32
Max	3.38	3.61	1.93	5.19
Min	1.54	0.64	1.52	1.04



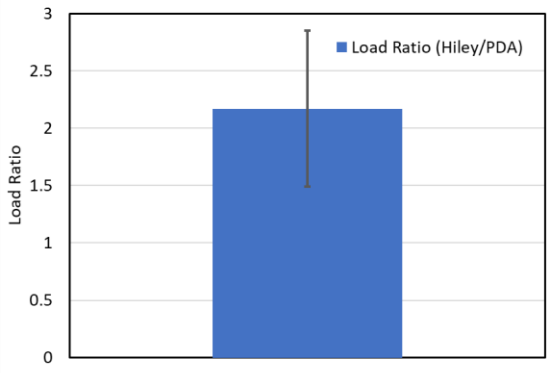
a) HP 310X79

b) HP 310X110

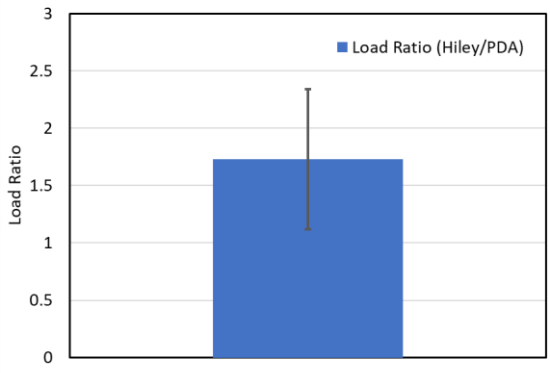
c) HP 310X132

d) HP 310X174

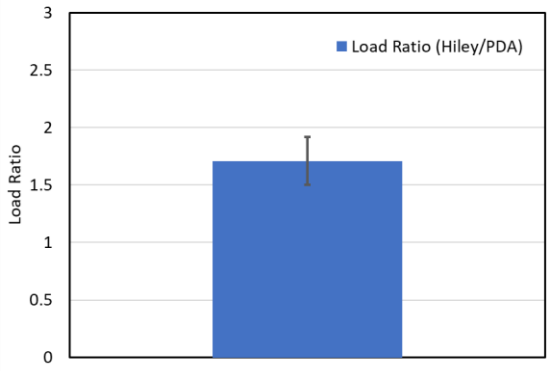
Figure 84 - PDA, pile capacity vs. Hiley, pile capacity based on H-pile size



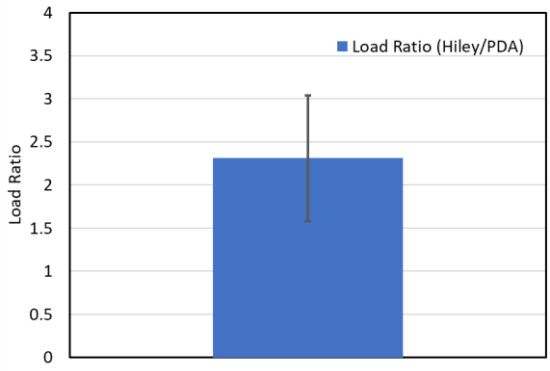
a) HP 310X79



b) HP 310X110



c) HP 310X132



d) HP 310X174

Figure 85 - Hiley to PDA Load ratio based on H-pile size

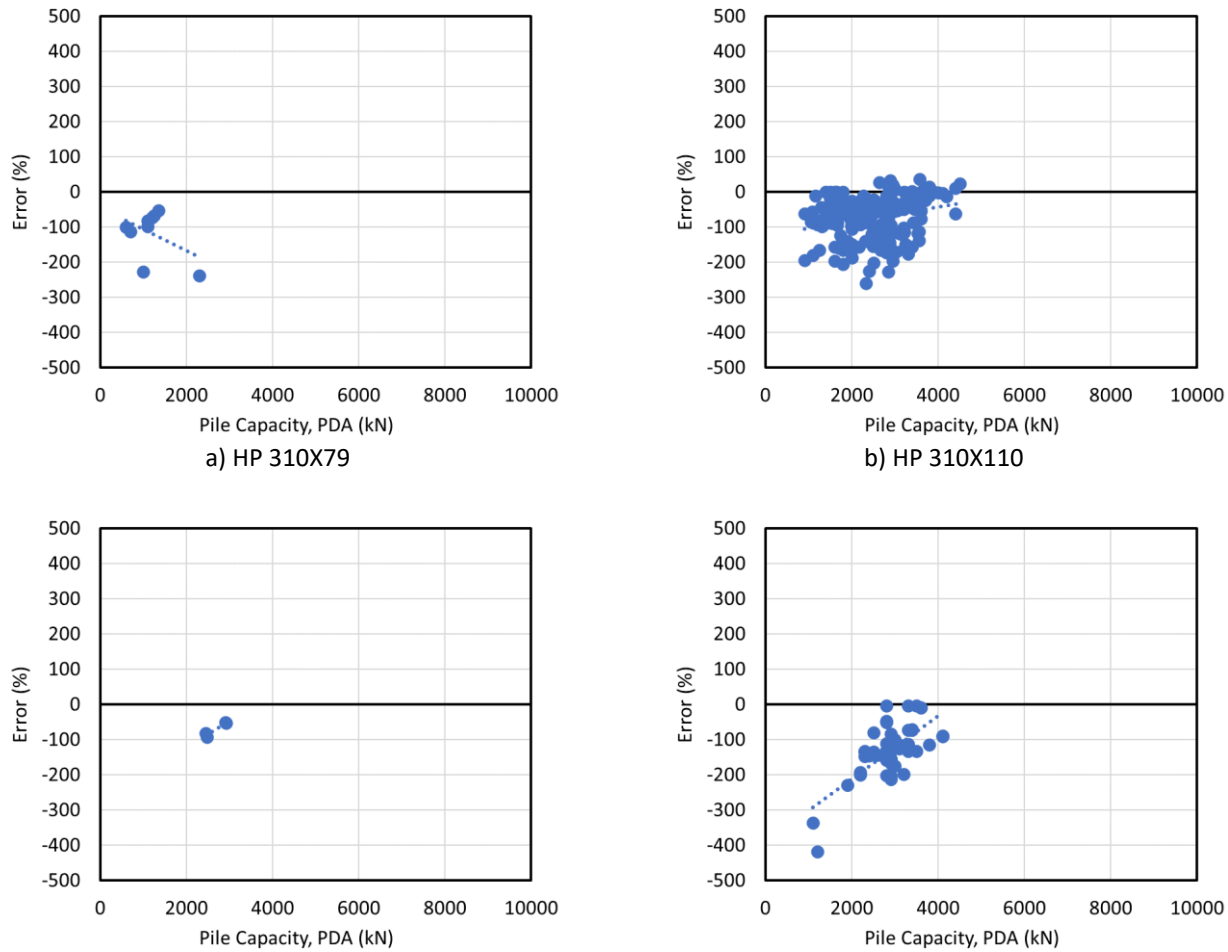


Figure 86 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on H-pile size

6.4.6 Pile Embedment Length

Figure 87 shows the relationship between the capacities obtained from Hiley tests to PDA tests based on pile embedment lengths. Figure 87a to Figure 87d show that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value and considerably more points landing between the 1:1 line and 1:2 line for all cases. Table 56 shows a summary of the dataset of Hiley and PDA tests based on pile embedment length.

Figure 88 and Table 57 show the load ratio of Hiley to PDA results based on pile embedment length. Figure 88a to Figure 88d and Table 57 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by about 50% for piles with embedment lengths between 24 m to 60 m and by 119% for piles with embedment lengths less than 12 m. For piles with embedment lengths between 12 m and 24 m, Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by about 80%. A trend is observed where the relationship between Hiley and PDA tests improves with increasing pile embedment length, however for cases Hiley provides a much higher estimate of pile resistance compared to PDA tests. Table 57 shows a summary of Hiley to PDA statistical results based on pile embedment length.

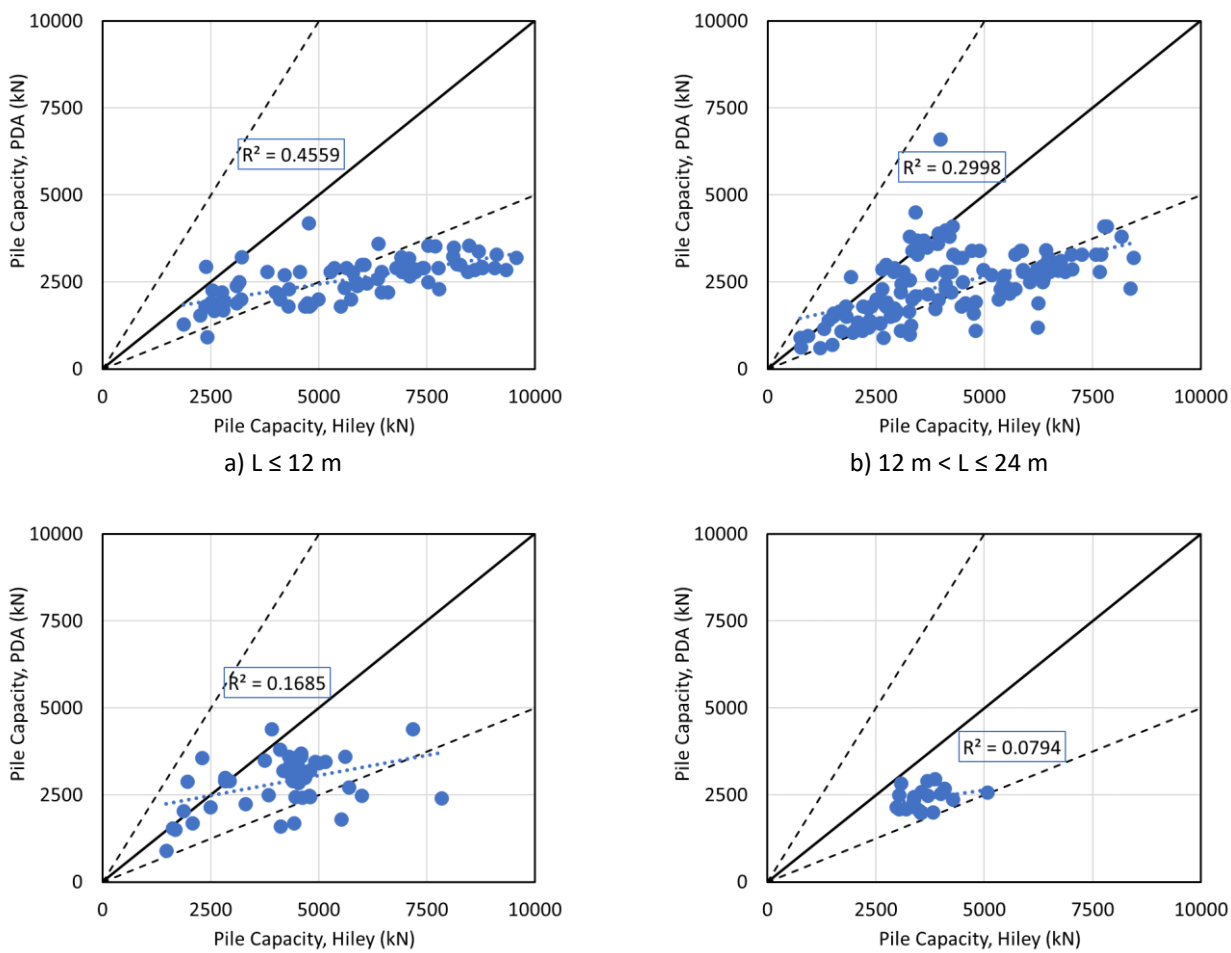
Figure 89 and Table 56 show a wide range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on pile embedment length.

Table 56 - Summary of the comparison between the capacities from Hiley and PDA based on the pile embedment length

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	Embedment Pile Length, L ≤ 12 m		
Number of Points	80		
Average	5687	2573	-119
Max	9571	4200	19
Min	1870	925	-238
R^2	0.46		---
Parameter	12 m < Embedment Pile Length, L ≤ 24 m		
Number of Points	133		
Average	4166	2421	-80
Max	8447	6600	40
Min	745	600	-419
R^2	0.3		---
Parameter	24 m < Embedment Pile Length, L ≤ 36 m		
Number of Points	48		
Average	4126	2862	-50
Max	7845	4400	36
Min	1466	900	-226
R^2	0.17		---
Parameter	36 m < Embedment Pile Length, L ≤ 60 m		
Number of Points	21		
Average	3589	2383	-52
Max	5070	2965	-8
Min	2973	1980	-97
R^2	0.08		---

Table 57 - Summary of the load ratio results of Hiley to PDA based on the pile embedment length

	Load Ratio (Hiley/Static)			
Parameter	L ≤ 12 m	12 m < L ≤ 24 m	24 m < L ≤ 36 m	36 m < L ≤ 60 m
No. of Points	80	133	48	21
Average	2.19	1.8	1.5	1.52
Std Dev, σ	0.62	0.72	0.55	0.23
COV (%)	28	40	37	15
Max	3.38	5.19	3.26	1.97
Min	0.81	0.6	0.64	1.08



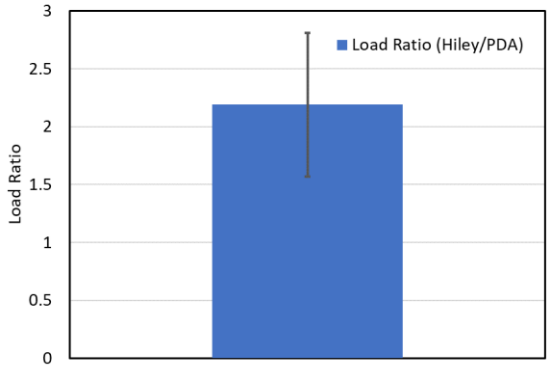
a) L ≤ 12 m

b) 12 m < L ≤ 24 m

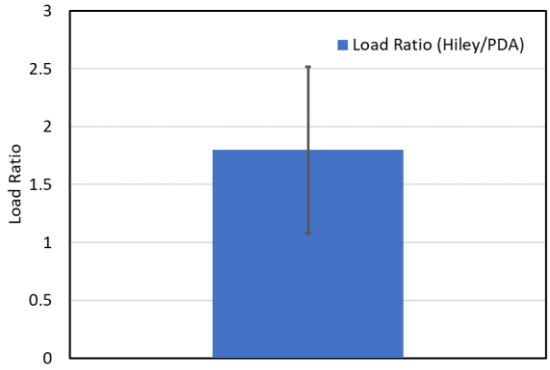
c) 24 m < L ≤ 36 m

d) 36 m < L ≤ 60 m

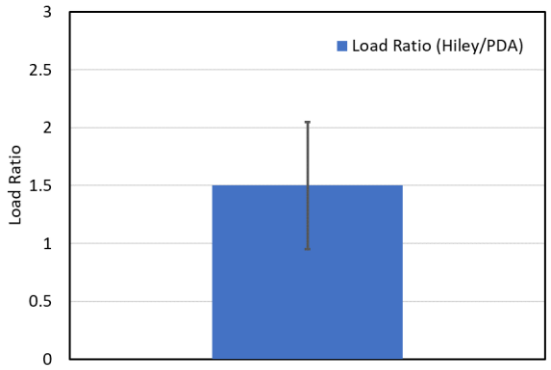
Figure 87 - PDA, pile capacity vs. Hiley, pile capacity based on pile embedment length



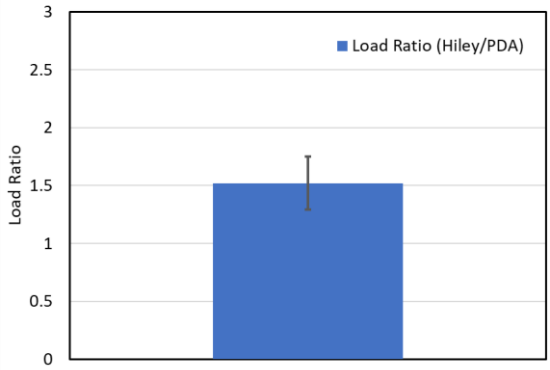
a) L ≤ 12 m



b) 12 m < L ≤ 24 m

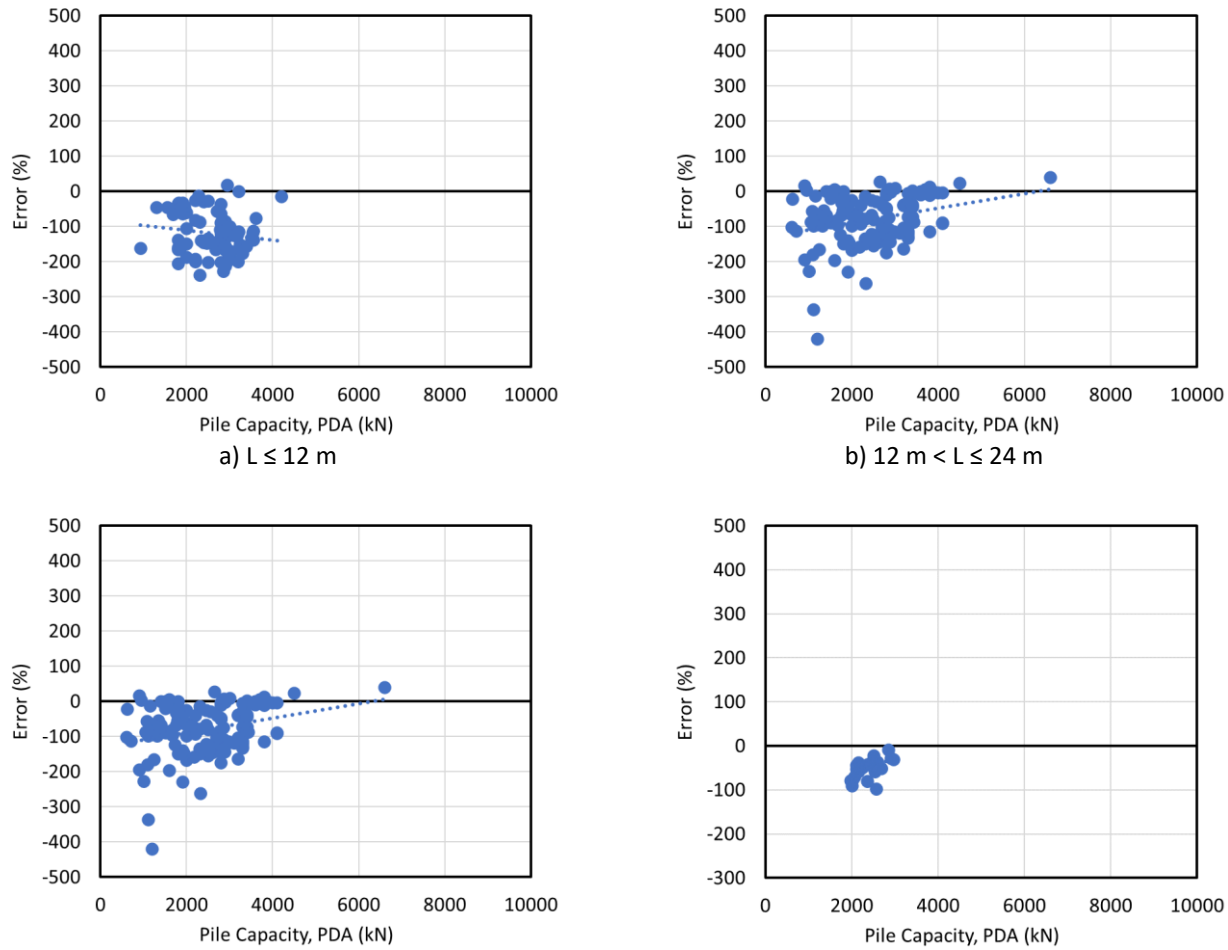


c) 24 m < L ≤ 36 m



d) 36 m < L ≤ 60 m

Figure 88 - Hiley to PDA Load ratio based on pile embedment length



a) L ≤ 12 m

b) 12 m < L ≤ 24 m

c) 24 m < L ≤ 36 m

d) 36 m < L ≤ 60 m

Figure 89 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on pile embedment lengths

6.4.7 Pile Splice

Figure 90 shows the relationship between the capacities obtained from Hiley tests to PDA tests based on pile splice. For piles which have been spliced, Figure 90a shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.25 and considerably more data points landing near the 1:2 line. For piles which have not been spliced, Figure 90b shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.29 and considerably more data points landing near the 1:2 line. Table 58 shows a summary of the dataset of Hiley and PDA tests based on pile splice.

Figure 91 and Table 59 show the load ratio of Hiley to PDA results. For piles which have been spliced, Figure 91a and Table 59 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 70% with a COV of 41%. For piles which have not been spliced, Figure 91b and Table 59 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 93% with a COV of 35%. Table 59 shows a summary of Hiley to PDA statistical results based on pile splice.

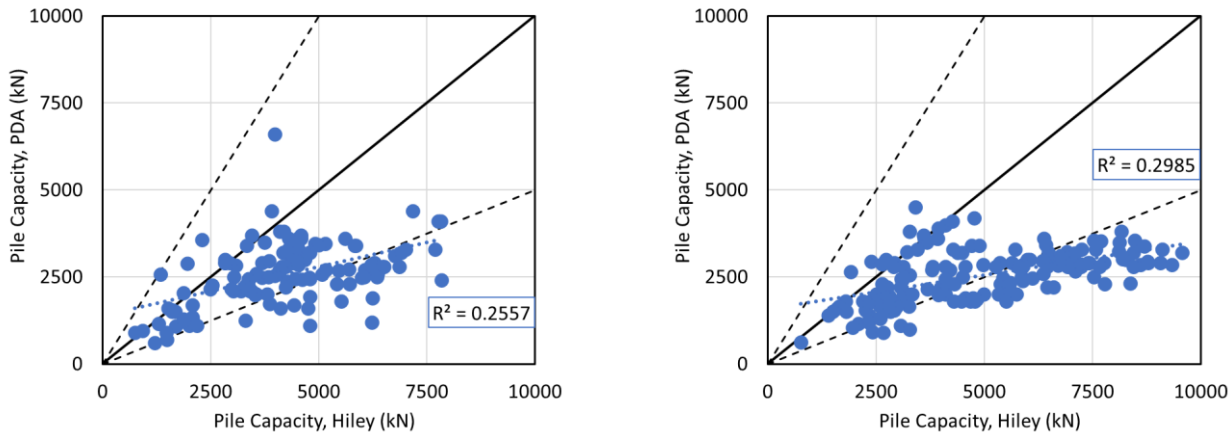
Figure 92 and Table 58 show the wide range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on pile splice. No difference was observed between piles which have been spliced and those which have not.

Table 58 - Summary of the comparison between the capacities from Hiley and PDA based on pile splice

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	With Splice		
Number of Points	121		
Average	4129	2549	-70
Max	7845	6600	48
Min	745	600	-419
R^2	0.26		--
Parameter	Without Splice		
Number of Points	163		
Average	4821	2520	-93
Max	9571	4500	28
Min	756	623	-261
R^2	0.3		--

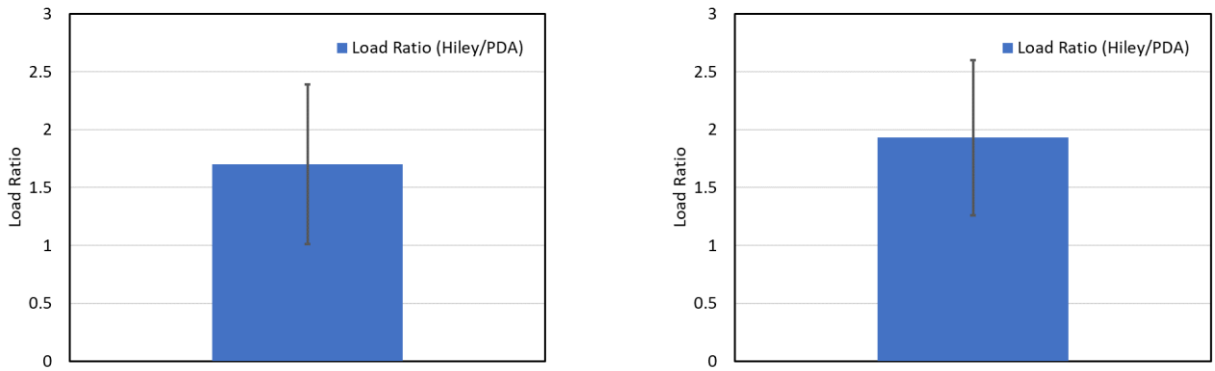
Table 59 - Summary of the load ratio results of Hiley to PDA based on pile splice

	Load Ratio (Hiley/Static)	
Parameter	With Splice	Without Splice
No. of Points	121	163
Average	1.7	1.93
Std Dev, σ	0.69	0.67
COV (%)	41	35
Max	5.19	3.61
Min	0.52	0.72



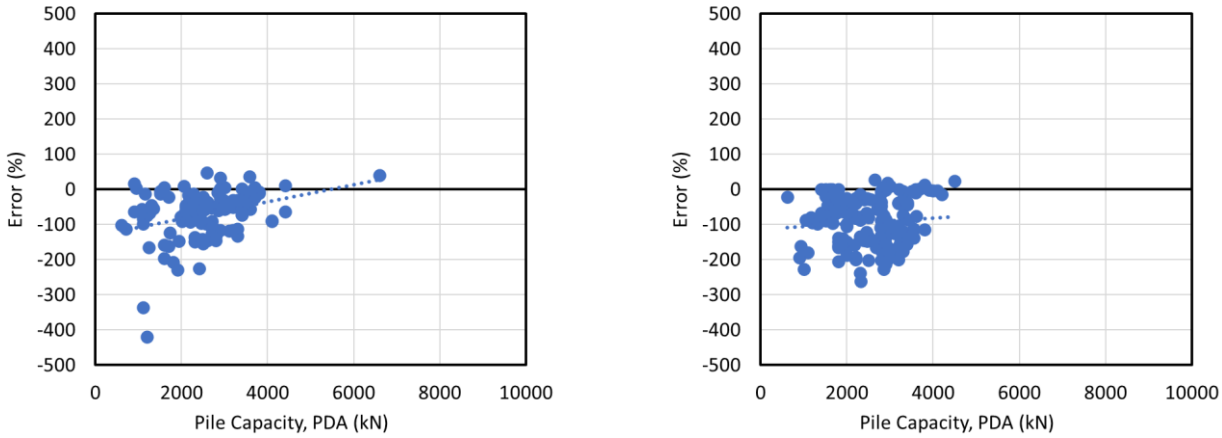
a) With Splice b) Without Splice

Figure 90 - PDA, pile capacity vs. Hiley, pile capacity based on pile splice



a) With Splice b) Without Splice

Figure 91 - Hiley to PDA Load ratio based on pile splice



a) With Splice b) Without Splice

Figure 92 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on pile splice

6.4.8 Pile Driving Event

Figure 93 shows the relationship between the capacities obtained from Hiley tests to PDA tests based on pile driving event. For pile tested at the end of initial driving (EOID), Figure 93a shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.36 and data points landing between the 1:1 line and the 1:2 line. For pile tested at the beginning of restrike (BOR), Figure 93b shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.21 and considerably more data points landing near the 1:2 line. For pile tested at the end of restrike (EOR), Figure 93c shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.16. Table 60 shows a summary of the dataset of Hiley and PDA tests based on driving event.

Figure 94 and Table 61 show the load ratio of Hiley to PDA results. For pile tested at the end of initial driving (EOID), Figure 94a and Table 61 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 68% with COV of 34%. For pile tested at the beginning of restrike (BOR), Figure 94b and Table 61 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 93% with a COV of 37%. For pile tested at the end of restrike (EOR), Figure 94c and Table 61 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 63% with a COV of 44%. Table 59 shows a summary of Hiley to PDA statistical results based on driving event. Although on average the load ratio is closer to unity for EOID and EOR events, in general there appears to be a similar distribution of data points for all cases.

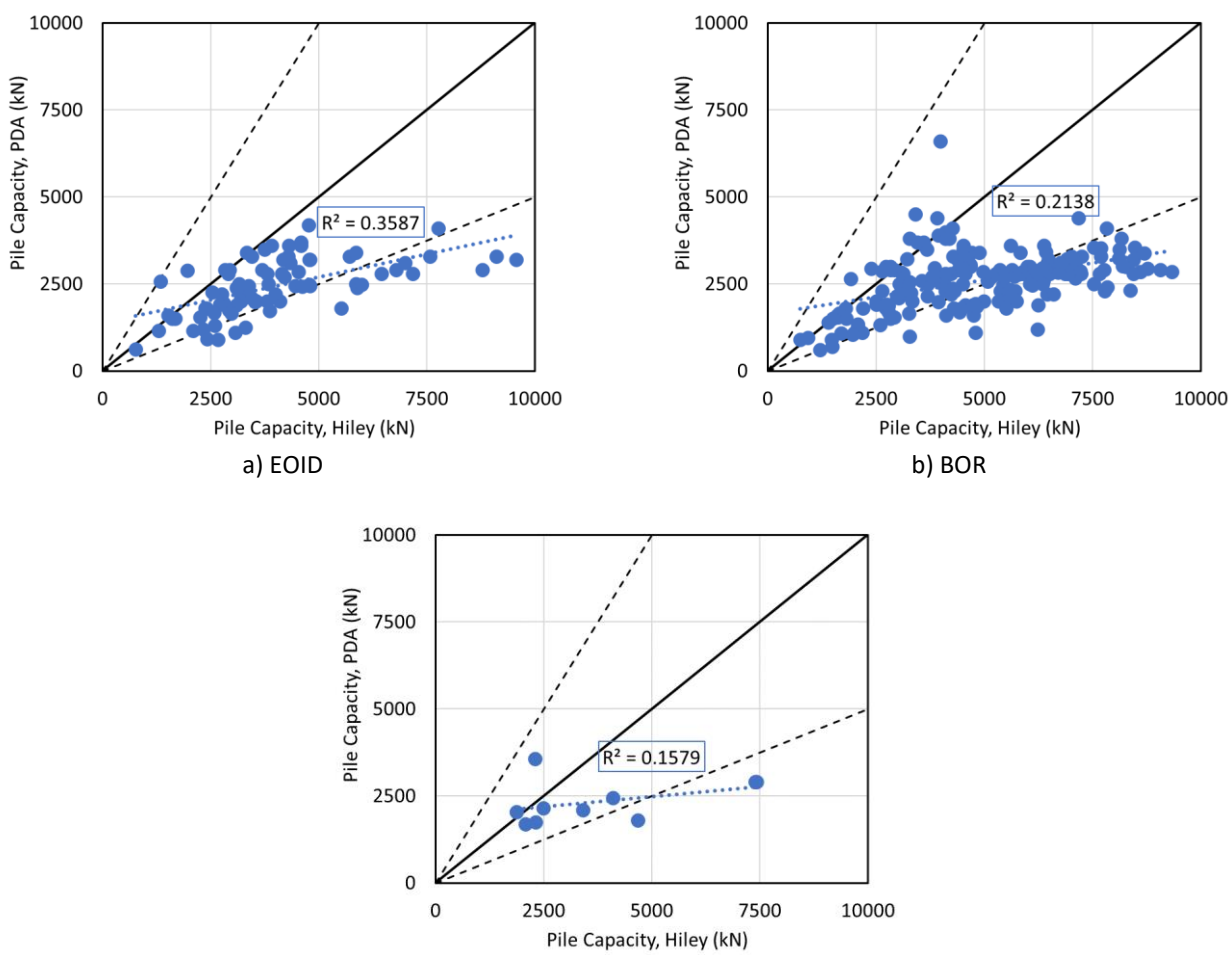
Figure 95 and Table 60 show the wide range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on driving event.

Table 60 - Summary of the comparison between the capacities from Hiley and PDA based on driving event

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	EOID		
Number of Points	81		
Average	3976	2426	-68
Max	9571	4200	48
Min	756	623	-206
R^2	0.36		---
Parameter	BOR		
Number of Points	186		
Average	4837	2586	-93
Max	9327	6600	40
Min	745	600	-419
R^2	0.21		---
Parameter	EOR		
Number of Points	10		
Average	3804	2337	-63
Max	7420	3576	36
Min	1868	1700	-160
R^2	0.16		---

Table 61 - Summary of the load ratio results of Hiley to PDA based on driving event

	Load Ratio (Hiley/Static)		
Parameter	EOID	BOR	EOR
No. of Points	81	186	10
Average	1.68	1.93	1.63
Std Dev, σ	0.57	0.72	0.72
COV (%)	34	37	44
Max	3.06	5.19	2.6
Min	0.52	0.6	0.64

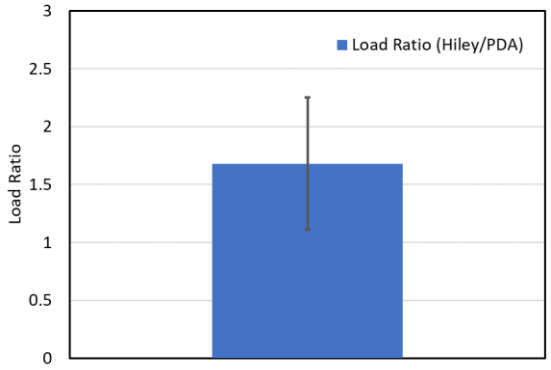


a) EOID

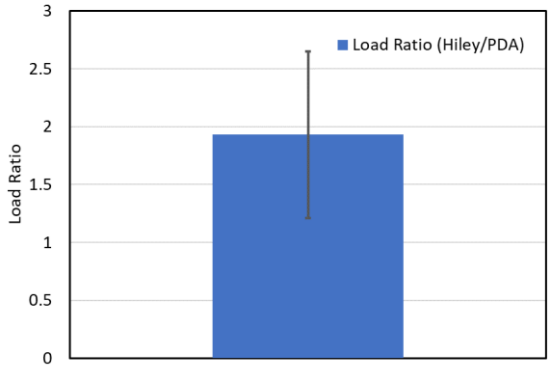
b) BOR

c) BOR

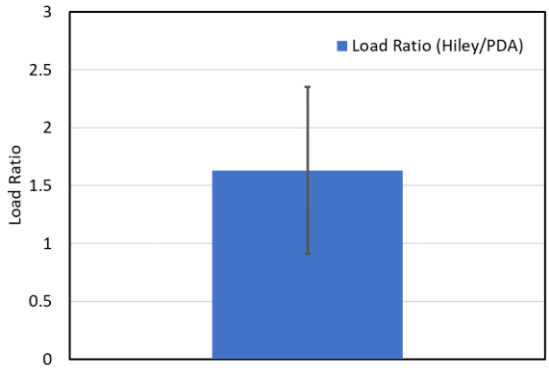
Figure 93 - PDA, pile capacity vs. Hiley, pile capacity based on driving event



a) EOID



b) BOR



c) EOR

Figure 94 – Hiley to PDA Load ratio based on driving event

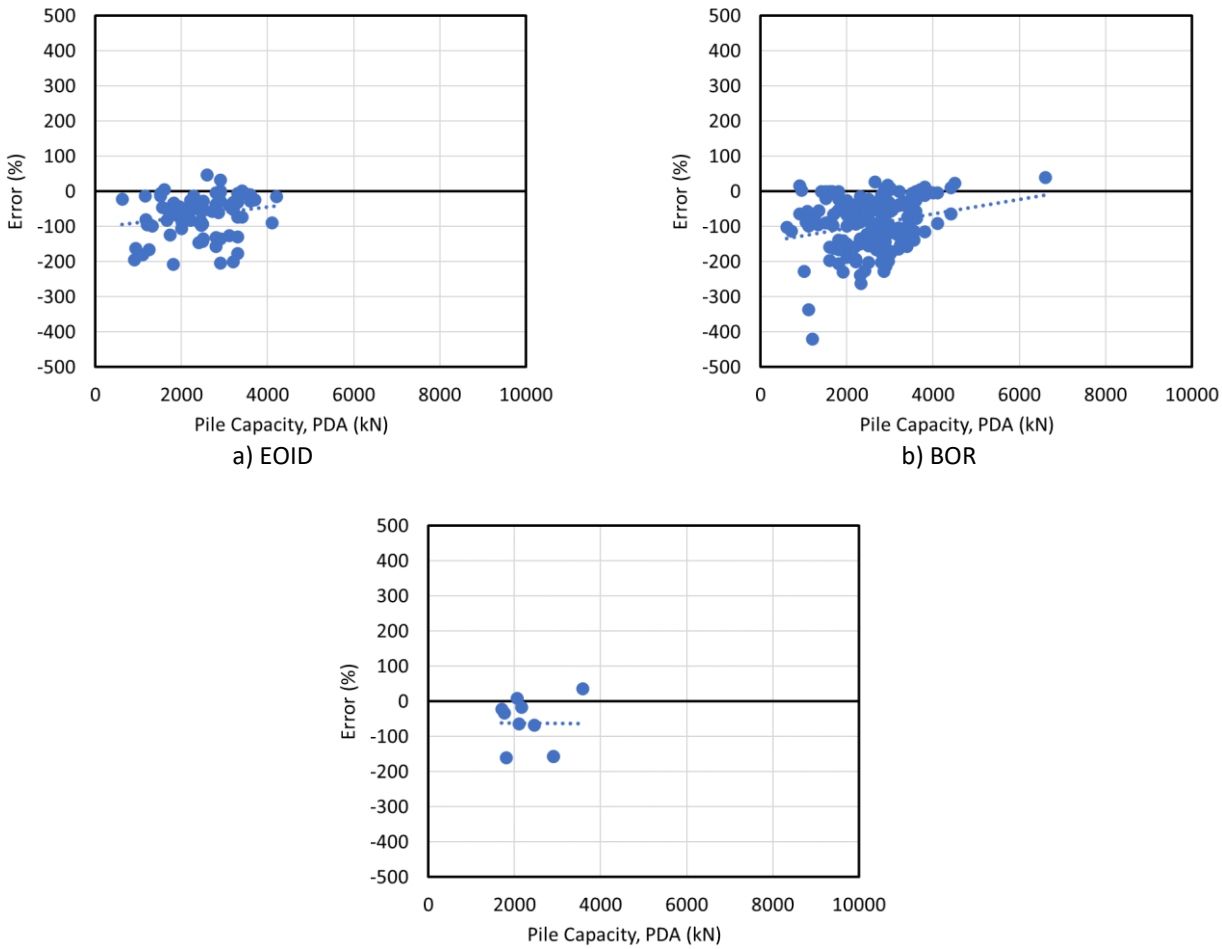


Figure 95 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on driving event

6.4.9 Hammer System

Figure 96 shows the relationship between the capacities obtained from Hiley tests to PDA tests based on hammer system. For piles driven with a diesel hammer, Figure 96a shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.27 and considerably more data points landing near the 1:2 line. For piles driven with a drop hammer, Figure 96b shows that there is excellent agreement between Hiley tests and PDA tests, with a high R^2 value of 0.96. Table 62 shows a summary of the dataset of Hiley and PDA tests based on hammer system.

Figure 97 and Table 63 show the load ratio of Hiley to PDA results. For piles driven with diesel hammer, Figure 97a, and Table 63 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 78%, with COV of 36%. For piles driven with drop hammer, Figure 97b and Table 59 show that the results of Hiley tests on average slightly overestimated the geotechnical capacity obtained from PDA tests by 3% with a COV of 5%. These values indicate that drop hammers are more accurate and reliable compared to diesel hammers. Table 63 shows a summary of Hiley to PDA statistical results based on hammer system.

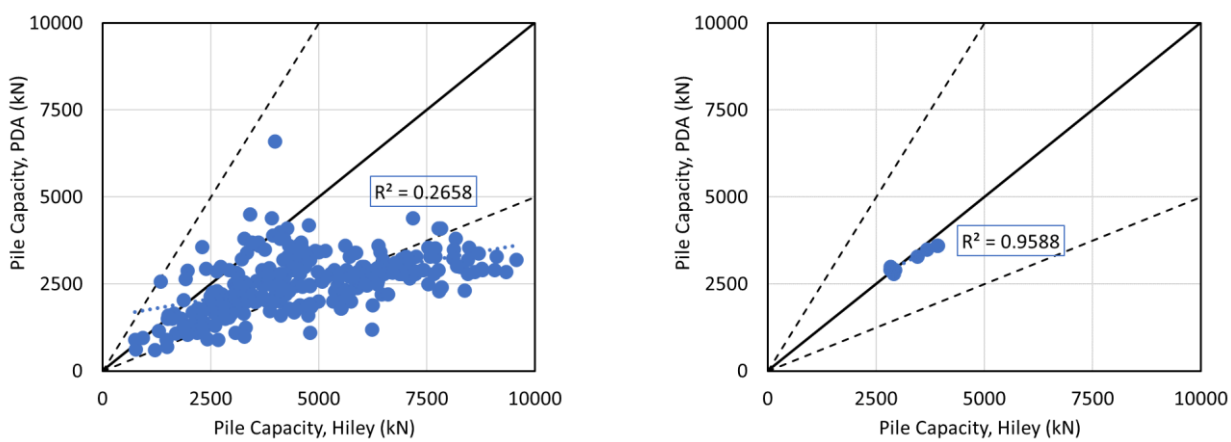
Figure 98 and Table 62 show the range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on hammer system. The range of error is lower for piles tested with a drop hammer (Figure 98b) compared to using diesel hammer (Figure 98a). It is worth mentioning that the piles were end bearing piles driven into cohesionless and cohesive soils.

Table 62 - Summary of the comparison between the capacities from Hiley and PDA based on hammer system

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	Diesel Hammer		
Number of Points	270		
Average	4622	2529	-87
Max	9571	6600	48
Min	745	600	-419
R^2	0.27		---
Parameter	Drop Hammer		
Number of Points	9		
Average	3255	3167	-2
Max	3919	3600	6
Min	2832	2800	-9
R^2	0.96		--

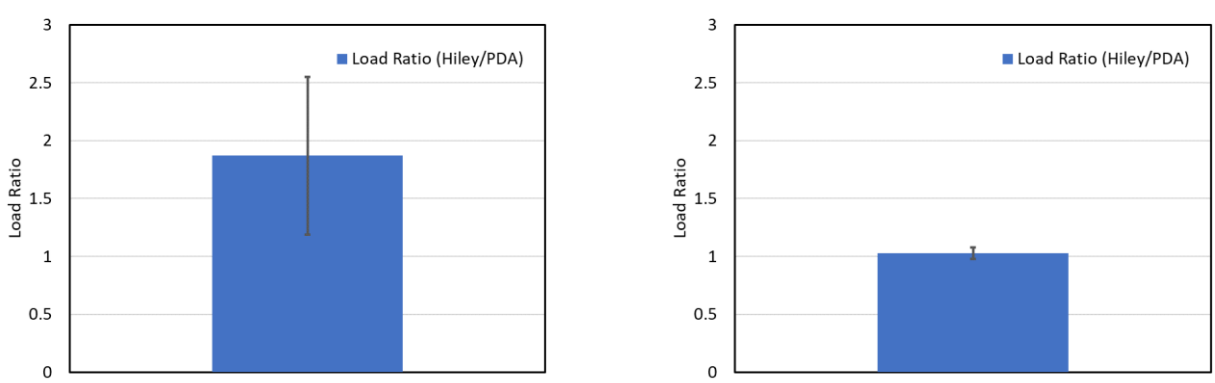
Table 63 - Summary of the load ratio results of Hiley to PDA based on hammer system

	Load Ratio (Hiley/Static)	
Parameter	Diesel Hammer	Drop Hammer
No. of Points	270	9
Average	1.87	1.03
Std Dev, σ	0.68	0.05
COV (%)	36	5
Max	5.19	1.09
Min	0.52	0.94



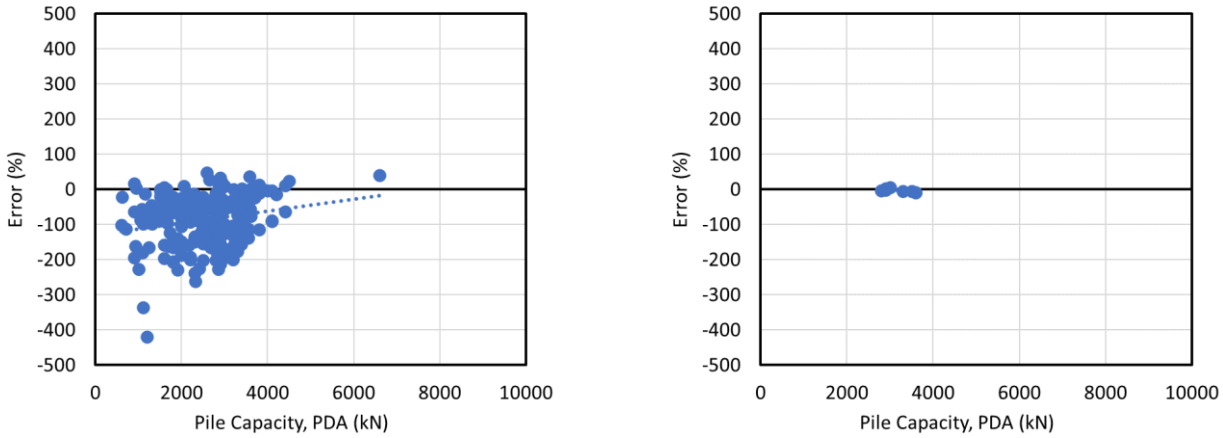
a) Diesel Hammer b) Drop Hammer

Figure 96 - PDA, pile capacity vs. Hiley, pile capacity based on hammer system



a) Diesel Hammer b) Drop Hammer

Figure 97 - Hiley to PDA Load ratio based on hammer system



a) Diesel Hammer b) Drop Hammer

Figure 98 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on hammer system

6.4.10 Pile Cushion

Figure 99 shows the relation between the capacities obtained from Hiley tests to PDA tests based on the use of a pile cushion. For piles driven with a pile cushion, Figure 99a shows that there is agreement between Hiley tests and PDA tests, with an R^2 value of 0.71 and some points near the 2:1 line. For piles driven without a pile cushion, Figure 99b shows there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.27. Table 64 shows a summary of the dataset of Hiley and PDA tests based on the use of pile cushion.

Figure 100 and Table 65 show the load ratio of Hiley to PDA testing results. For piles driven with a pile cushion, Figure 100a, and Table 65 show that the results of Hiley tests on average slightly overestimated the geotechnical capacity obtained from PDA tests by 3% with a COV of 22%. For piles driven without a pile cushion, Figure 100b, and Table 65 show that the results of Hiley tests on average overestimated the geotechnical capacity obtained from PDA tests by 88% with a COV of 36%. Table 65 shows a summary of Hiley to PDA statistical results based on the use of pile cushion.

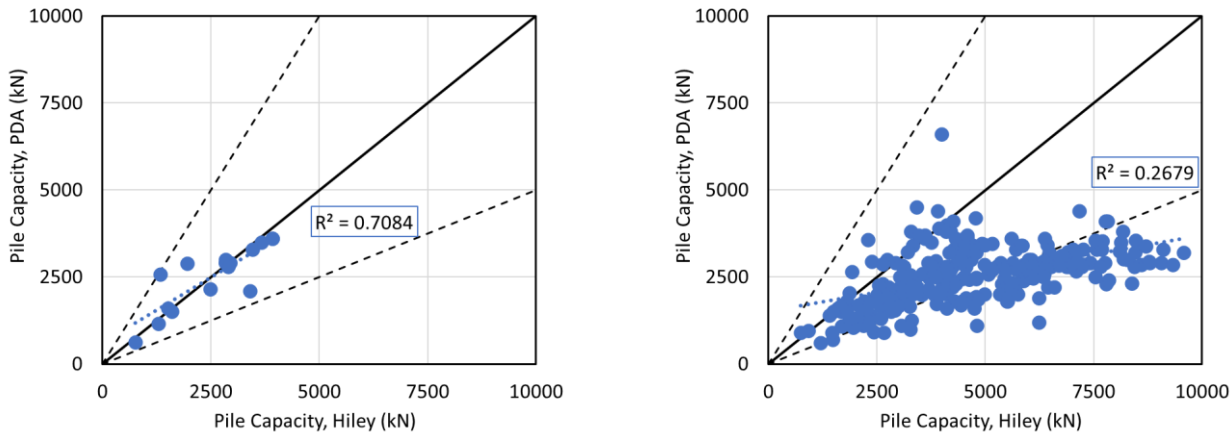
Figure 101 and Table 64 show the range of the percentage of error for Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on the use of a pile cushion during driving. The range of error is lower for piles driven with a cushion (Figure 101a) compared to those driven without a cushion (Figure 101b).

Table 64 - Summary of the comparison between the capacities from Hiley and PDA based on use of pile cushion

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	Pile Driven with Cushion		
Number of Points	17		
Average	2567	2536	-3
Max	3919	3600	48
Min	756	623	-63
R^2	0.71		--
Parameter	Pile Driven without Cushion		
Number of Points	267		
Average	2567	2536	-3
Max	3919	3600	48
Min	756	623	-63
R^2	0.71		--

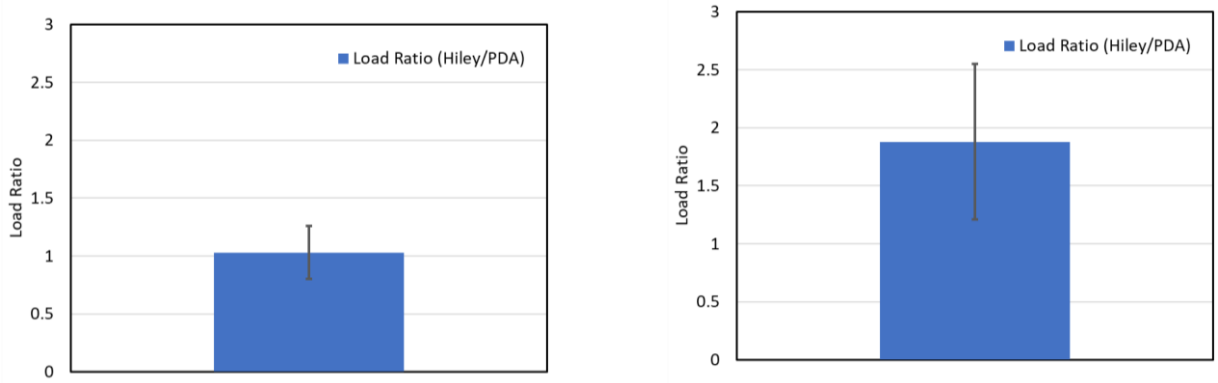
Table 65 - Summary of the load ratio results of Hiley to PDA based on the use of pile cushion

	Load Ratio (Hiley/Static)	
Parameter	With Driving Shoe/Bearing Point	Without Driving Shoe/Bearing Point
No. of Points	17	267
Average	1.03	1.88
Std Dev, σ	0.23	0.67
COV (%)	22	36
Max	1.63	5.19
Min	0.52	0.6



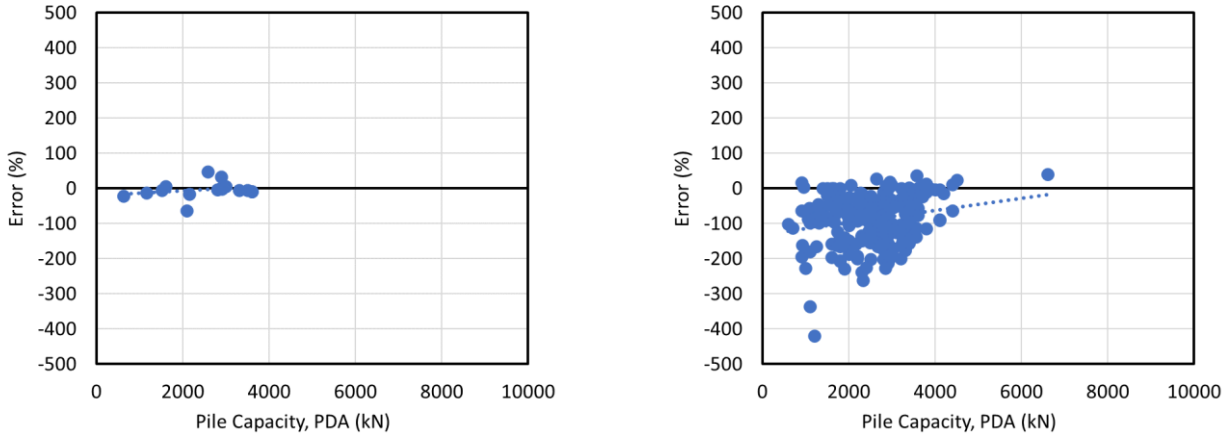
a) With cushion b) Without cushion

Figure 99 - PDA, pile capacity vs. Hiley, pile capacity based on the use of pile cushion



a) With cushion b) Without cushion

Figure 100 - Hiley to PDA Load ratio based on the use of pile cushion



a) With cushion b) Without cushion

Figure 101 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on the use of pile cushion

6.4.11 Pile Driving Shoe/Bearing Point

Figure 102 shows the relationship between the capacities obtained from Hiley tests to PDA tests based on using a pile shoe/bearing point during driving. For piles driven with a driving shoe/bearing point, Figure 102a shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.24 and considerably more data points landing near the 1:2 line. For piles driven without a driving shoe/bearing point, Figure 102b also shows there is relatively poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.28. Although there are far fewer datapoints for piles driven without a cushion, there appears to be a similar distribution of data points. Table 66 shows a summary of the dataset for Hiley and PDA tests based on the use of a pile driving shoe/bearing point.

Figure 103 and Table 67 show the load ratio of Hiley to PDA results. For piles driven with a driving shoe/bearing point, Figure 103a, and Table 67 show that the results of Hiley tests on average overestimated the geotechnical capacity obtained from PDA tests by 84% with a COV of 37%. For piles driven without a driving shoe/bearing point, Figure 103b, and Table 67 show that the results of Hiley tests on average overestimated the geotechnical capacity obtained from PDA tests by 29% with a COV of 60%. Table 67shows a summary of Hiley to PDA statistical results based on the use of pile driving shoe/bearing point.

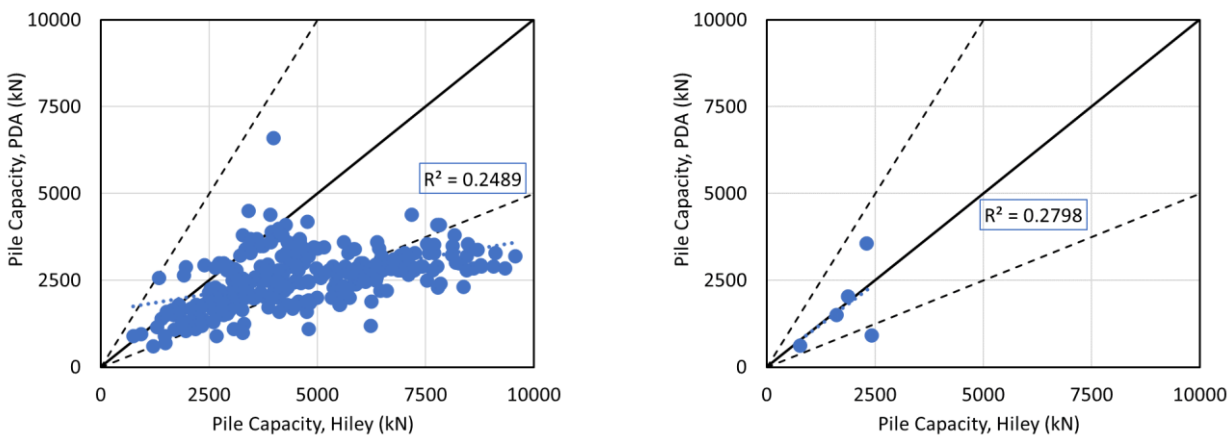
Figure 104 and Table 66 show the range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on the use of pile driving shoe/bearing point. The range of error is lower in case of not using pile driving shoe/bearing point (Figure 104b) than in case of using pile driving shoe/bearing point (Figure 104a).

Table 66 - Summary of the comparison between the capacities from Hiley and PDA based on pile driving shoe/bearing point

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	With Driving Shoe/Bearing Point		
Number of Points	279		
Average	4575	2547	-84
Max	9571	6600	48
Min	745	600	-419
R^2	0.25		--
Parameter	Without Driving Shoe/Bearing Point		
Number of Points	5		
Average	1788	1737	-29
Max	2420	3576	36
Min	756	623	-162
R^2	0.28		--

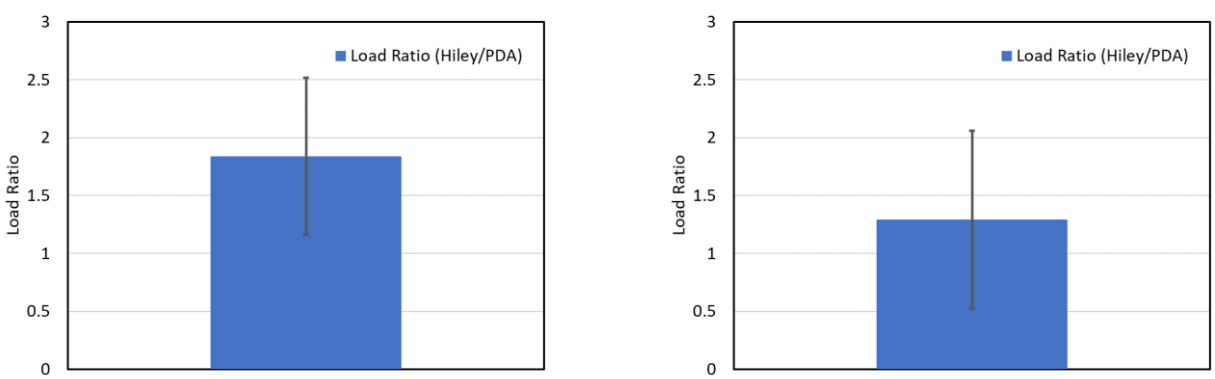
Table 67 - Summary of the load ratio results of Hiley to PDA based on pile driving shoe/bearing point

	Load Ratio (Hiley/Static)	
Parameter	With Driving Shoe/Bearing Point	Without Driving Shoe/Bearing Point
No. of Points	279	5
Average	1.84	1.29
Std Dev, σ	0.68	0.77
COV (%)	37	60
Max	5.19	2.62
Min	0.52	0.64



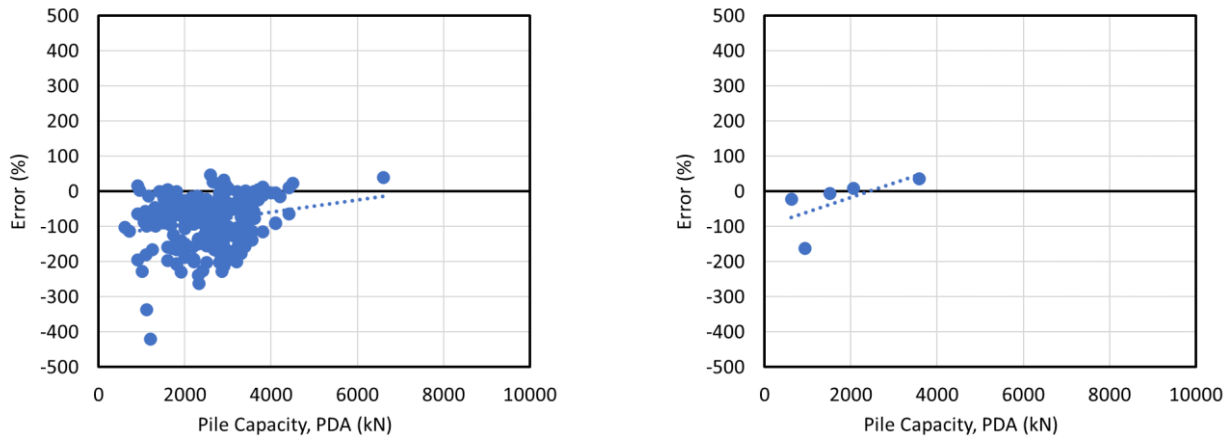
a) With Shoe b) Without Shoe

Figure 102 - PDA, pile capacity vs. Hiley, pile capacity based on driving shoe/bearing point



a) With Shoe b) Without Shoe

Figure 103 - Hiley to PDA Load ratio based on pile driving shoe/bearing point



a) With Shoe b) Without Shoe

Figure 104 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on pile driving shoe/bearing point

6.4.12 Hammer Rated Energy

Figure 105 shows the relation between the capacities obtained from Hiley tests to PDA tests based on hammer rated energy. For piles installed with a hammer rated energy between 30 kJ and 60 kJ, Figure 105a shows that there is relatively good agreement between Hiley tests and PDA tests, with an R^2 value of 0.67 and considerably some data points landing between the line 1:1 and the 1:2 line. For piles installed with a hammer rated energy between 60 kJ and 90 kJ, Figure 105b shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.24 and considerably more data points landing near the 1:2 line. For piles installed with a hammer rated energy of more than 90 kJ, Figure 105c shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.14 and considerably more data points landing near the 1:2 line. Table 68 shows a summary of the dataset of Hiley and PDA tests based on the hammer rated energy.

Figure 106 and Table 69 show the load ratio of Hiley to PDA results. For piles driven with hammer rated energy between 30 kJ and 60 kJ, Figure 106a, and Table 69 show that the results of Hiley tests on average overestimated the geotechnical capacity obtained from PDA tests by 44% with a COV of 29%. For piles driven with hammer rated energy between 60 kJ and 90 kJ, Figure 106b, and Table 69 show that the results of Hiley tests on average overestimated the geotechnical capacity obtained from PDA tests by 57% with a COV of 49%. For piles driven with hammer rated energy more than 90 kJ, Figure 106c, and Table 69 show that the results of Hiley tests on average overestimated the geotechnical capacity obtained from PDA tests by 96% with a COV of 35%. A trend is observed where the load ratio of Hiley to PDA increases with increasing hammer rated energy. Table 69 shows a summary of Hiley to PDA statistical results based on the hammer rated energy.

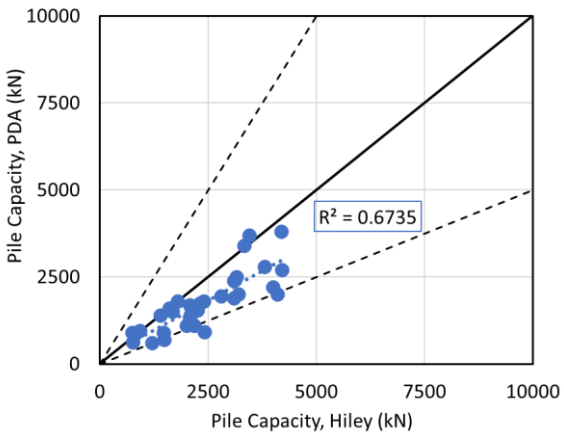
Figure 107 and Table 68 show the range of the percentage of error for Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on hammer system. The range of error is lower for piles driven by hammers with low rated energy (between 30 kJ to 60 kJ, Figure 107a) for piles driven by hammers with larger rated energies (Figure 107b and Figure 107c). The range of percentage of error increased with increasing the hammer rated energy.

Table 68 - Summary of the comparison between the capacities from Hiley and PDA based on hammer rated energy

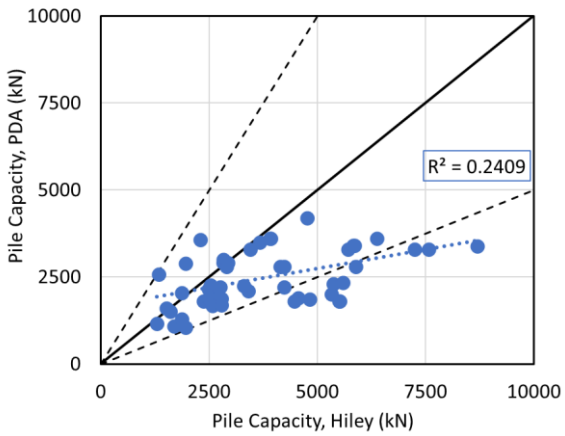
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	Energy, 30 kJ < E ≤ 60 kJ		
Number of Points	33		
Average	2394	1745	-44
Max	4200	3800	17
Min	745	600	-162
R^2	0.67		---
Parameter	Energy, 60 kJ < E ≤ 90 kJ		
Number of Points	50		
Average	3774	2468	-57
Max	8700	4200	48
Min	1290	1050	-206
R^2	0.24		---
Parameter	Energy, E> 90 kJ		
Number of Points	201		
Average	5063	2678	-96
Max	9571	6600	40
Min	1500	905	-419
R^2	0.14		---

Table 69 - Summary of the load ratio results of Hiley to PDA based on hammer rated energy

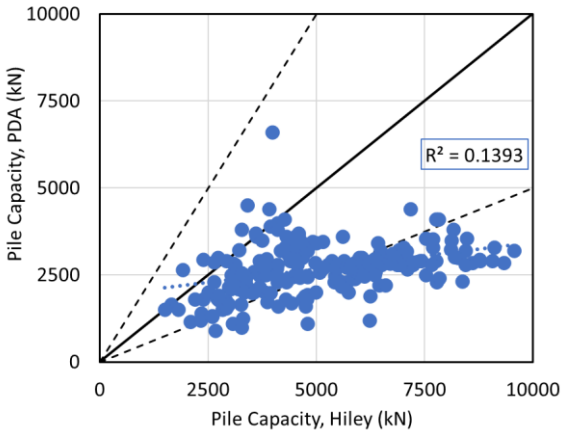
	Load Ratio (Hiley/Static)		
Parameter	30 kJ < E ≤ 60 kJ	60 kJ < E ≤ 90 kJ	E > 90 kJ
No. of Points	33	50	201
Average	1.44	1.57	1.96
Std Dev, σ	0.42	0.63	0.69
COV (%)	29	40	35
Max	2.62	3.06	5.19
Min	0.83	0.52	0.6



a) 30 kJ < E ≤ 60 kJ

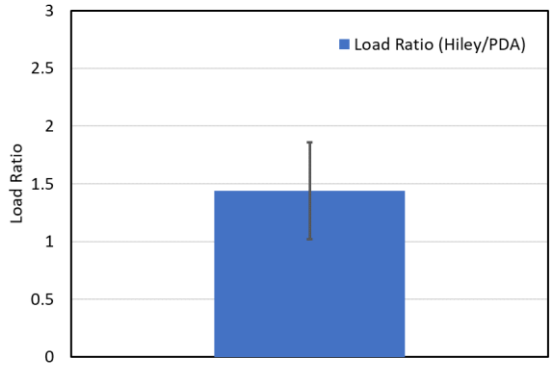


b) 60 kJ < E ≤ 90 kJ

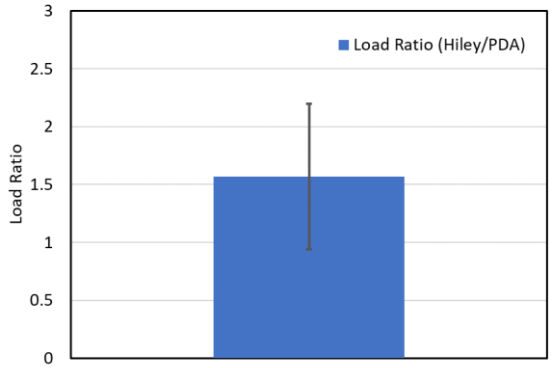


c) E > 90 kJ

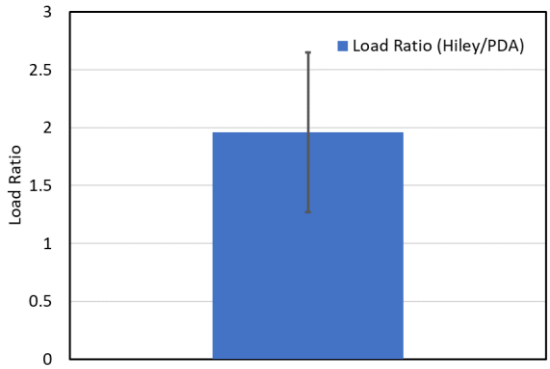
Figure 105 - PDA, pile capacity vs. Hiley, pile capacity based on hammer rated energy



a) 30 kJ < E ≤ 60 kJ

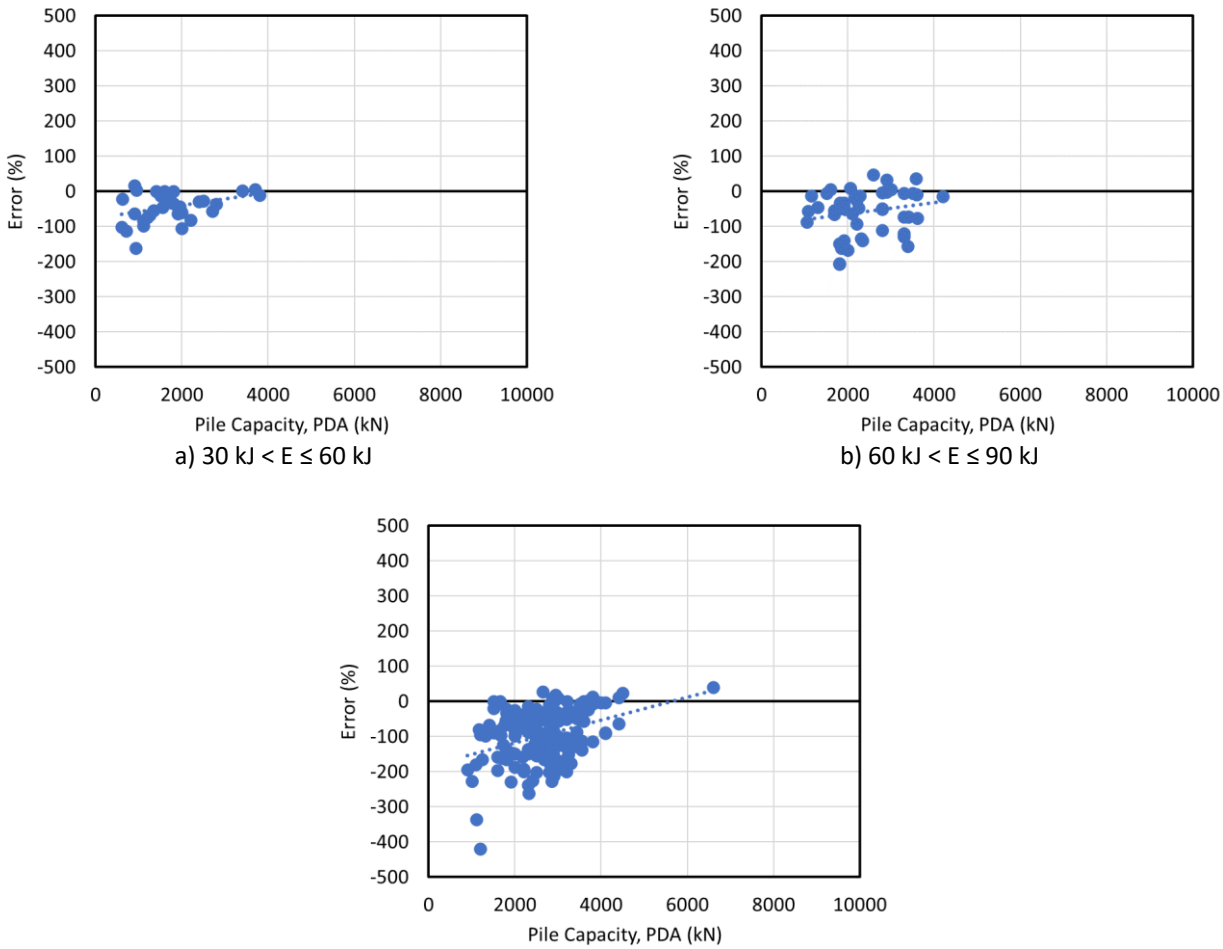


b) 60 kJ < E ≤ 90 kJ



c) E > 90 kJ

Figure 106 – Hiley to PDA Load ratio based on hammer rated energy



a) 30 kJ < E ≤ 60 kJ

b) 60 kJ < E ≤ 90 kJ

c) E > 90 kJ

Figure 107 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on hammer rated energy

6.4.13 Driving Resistance

Figure 108 shows the relationship between the capacities obtained from Hiley tests to PDA tests based on driving resistance. For piles driven with high driving resistance, Figure 108a shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.19 and most data points landing between the line 1:1 and the 1:2 line. For piles driven with intermediate driving resistance, Figure 108b shows that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.43 and considerably more data points landing near the 1:2 line. For piles driven with low driving resistance, Figure 108c shows that there is poor agreement between Hiley tests and PDA tests, with a very low R^2 (0) and considerably more data points landing near the 1:2 line. Table 70 shows a summary comparison of the dataset of Hiley and PDA tests based on pile driving resistance.

Figure 109 and Table 71 show the load ratio of Hiley to PDA results. For piles driven with high driving resistance, Figure 109a, and Table 71 shows that the results of Hiley tests on average overestimated the geotechnical capacity obtained from PDA tests by 52% with a COV of 35%. For piles driven with intermediate driving resistance, Figure 109b, and Table 71 show that the results of Hiley tests on average overestimated the geotechnical capacity obtained from PDA tests by 100% with a COV of 35%. For piles driven with low driving resistance, Figure 109c, and Table 71 show that the results of Hiley tests on average overestimated the geotechnical capacity obtained from PDA tests by 87% with a COV of 32%. Table 71 shows a summary of Hiley to PDA statistical results based on pile driving resistance.

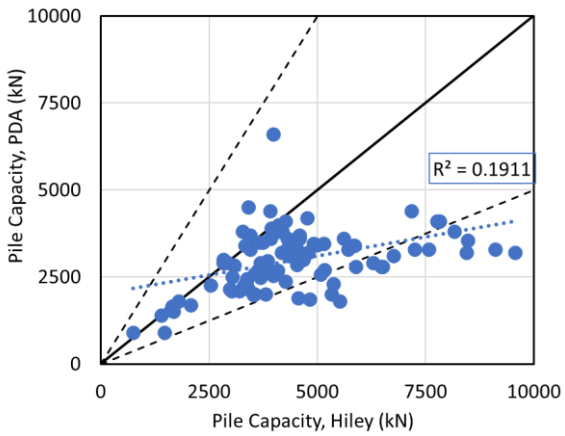
Figure 110a to Figure 110c and Table 70 show the range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on driving resistance.

Table 70 - Summary of the comparison between the capacities from Hiley and PDA based on driving resistance

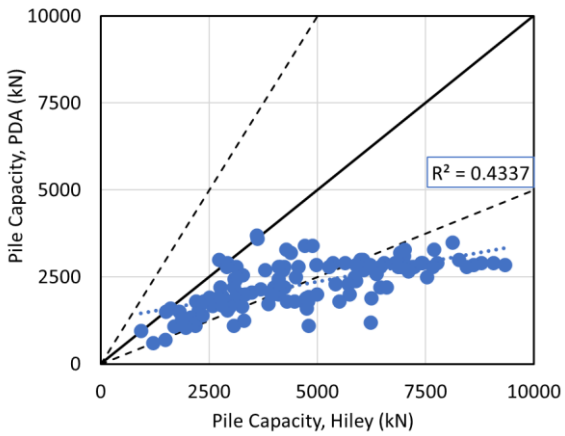
	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	High		
Number of Points	95		
Average	4428	2976	-52
Max	9571	6600	40
Min	745	900	-206
R^2	0.19		---
Parameter	Intermediate		
Number of Points	126		
Average	4476	2247	-100
Max	9327	3700	9
Min	919	600	-419
R^2	0.43		---
Parameter	Low		
Number of Points	7		
Average	2591	1507	-87
Max	2828	2300	-14
Min	2324	905	-194
R^2	0		---

Table 71 - Summary of the load ratio results of Hiley to PDA based on driving resistance

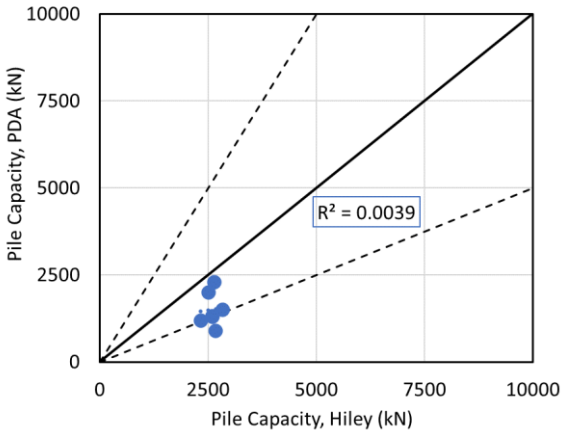
	Load Ratio (Hiley/Static)		
Parameter	High	Intermediate	Low
No. of Points	95	126	7
Average	1.52	2	1.87
Std Dev, σ	0.53	0.7	0.59
COV (%)	35	35	32
Max	3.06	5.19	2.94
Min	0.6	0.91	1.14



a) High

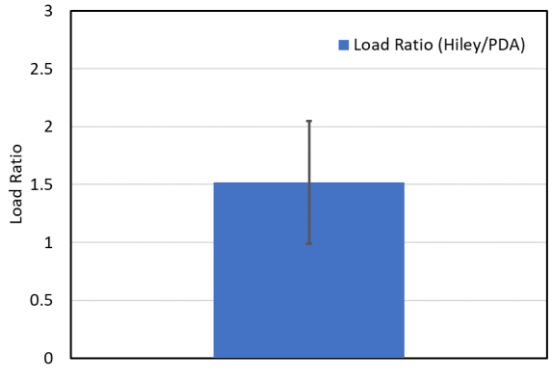


b) Intermediate

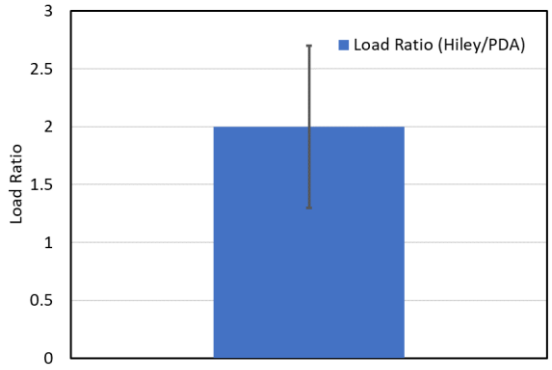


c) Low

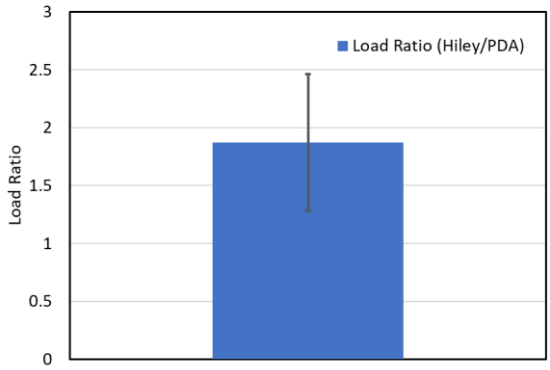
Figure 108 - PDA, pile capacity vs. Hiley, pile capacity based on driving resistance



a) High

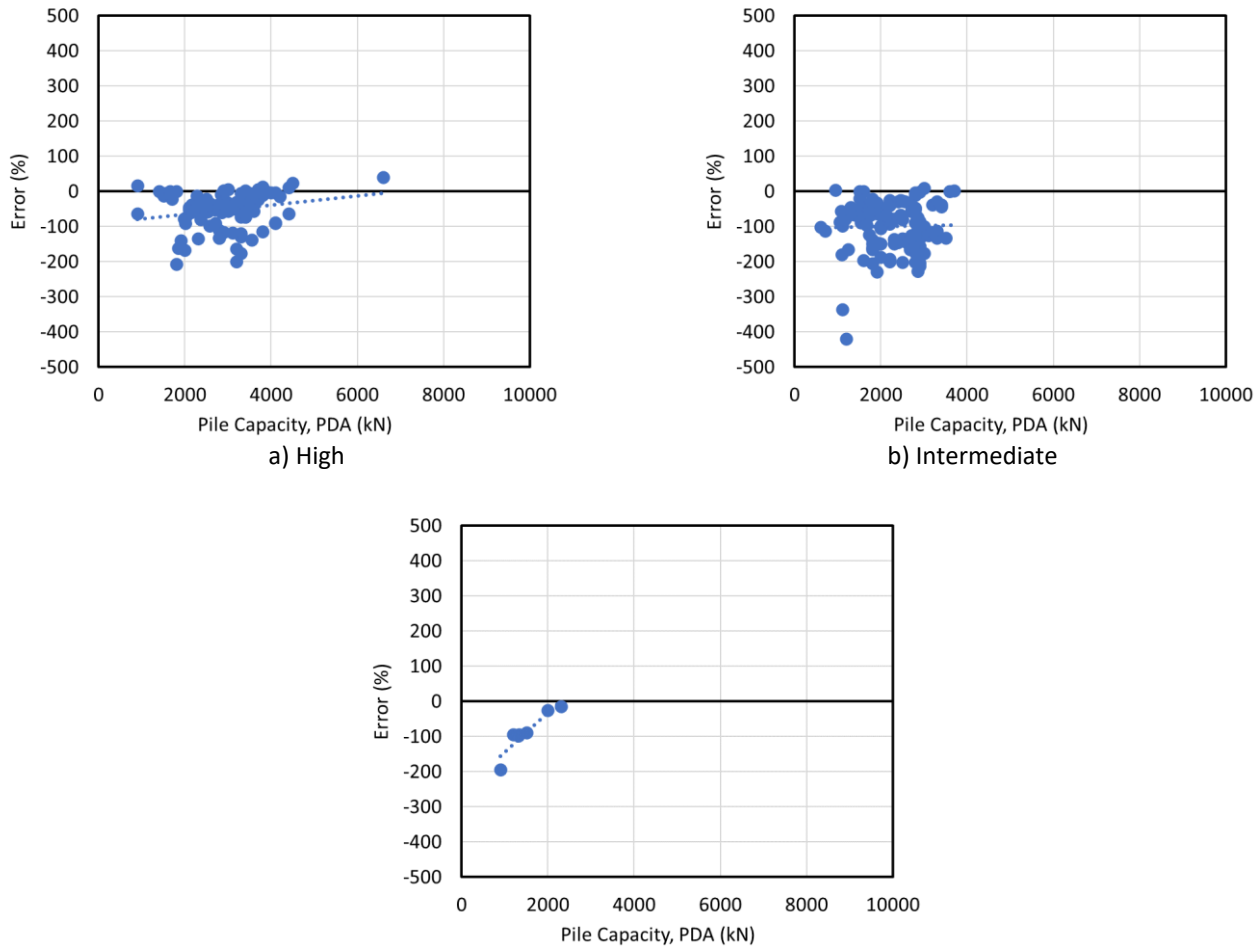


b) Intermediate



c) Low

Figure 109 – Hiley to PDA Load ratio based on driving resistance



a) High

b) Intermediate

c) Low

Figure 110 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on driving resistance

6.4.14 Diesel Hammer Specification

Figure 111 shows the relation between the capacities obtained from Hiley tests to PDA tests based on diesel hammer specification. For Berminghammer diesel hammers, Figure 111a show that there is poor agreement between Hiley tests and PDA tests, with a low R^2 value of 0.29 and considerably more data points landing near the 1:2 line. For Delmag hammers, Figure 111b shows that there is relatively good agreement between Hiley tests and PDA tests, with an R^2 value of 0.7. Most of the dataset points are located with the 1:2 line and 1:1 line. For Pileco hammers, Figure 111c shows there is relatively good agreement between Hiley tests and PDA tests, with an R^2 of 0.56; however, the data was collected from one site. For APE hammers (Figure 111c), no conclusion can be build based on 1 point. Table 72 shows a summary of the dataset of Hiley and PDA tests based on diesel hammer specification.

Figure 112 and Table 73 shows the load ratio of Hiley to PDA results. For Berminghammer diesel hammers, Figure 112a and Table 73 show that the results of Hiley tests on average greatly overestimated the geotechnical capacity obtained from PDA tests by 105% with a COV of 33%. For Delmag hammers, Figure 112b and Table 73 and show that the results of Hiley tests on overestimated the geotechnical capacity obtained from PDA tests by 41% with a COV of 23%. For Pileco, Figure 112c and Table

73 show that the results of Hiley tests overestimated the geotechnical capacity obtained from PDA tests by 16% with a COV of 17%. For APE hammer (Figure 112c), no conclusion can be made based on 1 point.

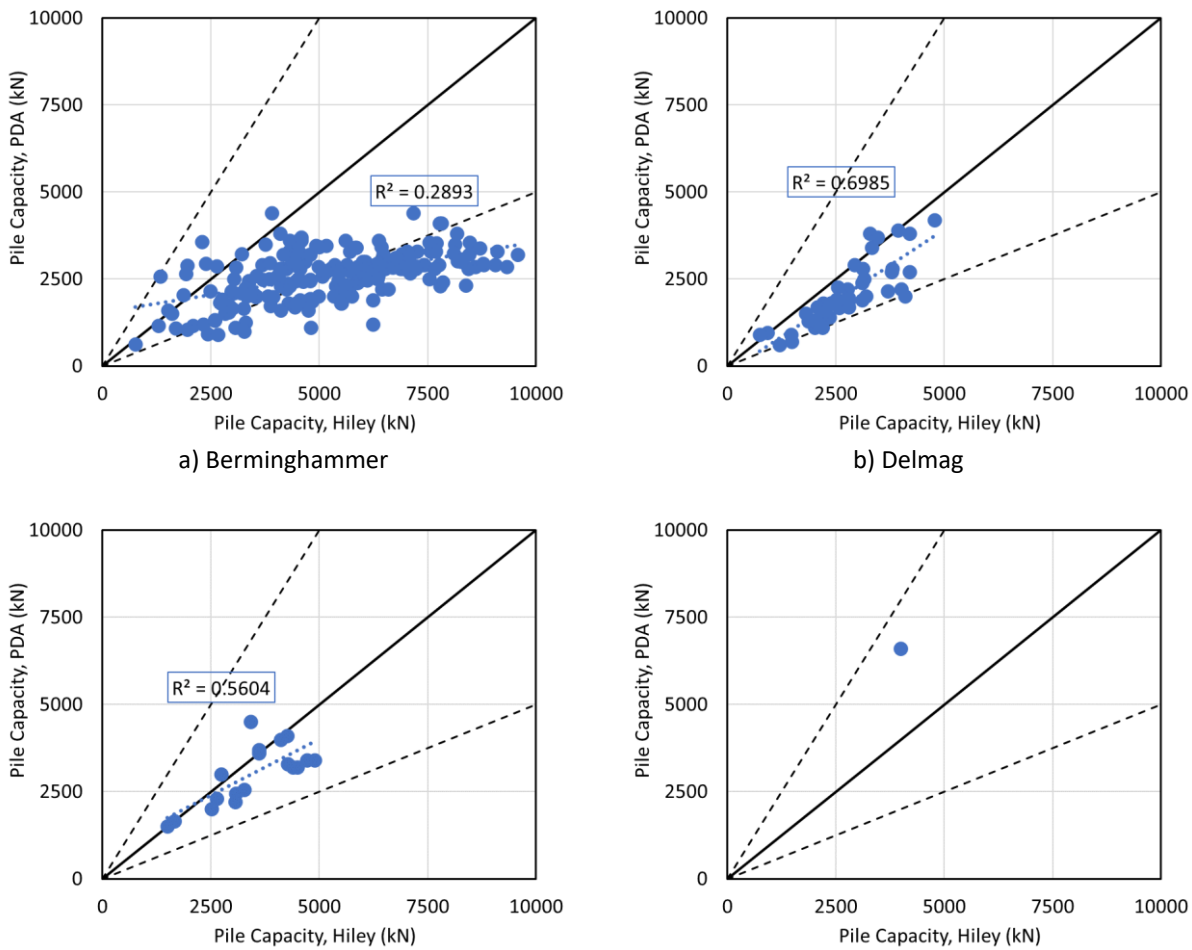
Figure 113 and Table 72 show the range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on pile type. The graphs and table show that Pileco hammers have the lowest average percent error and smallest minimum and maximum range of values.

Table 72 - Summary of the comparison between the capacities from Hiley and PDA based on diesel hammer specification

	Ultimate Compression Resistance, Hiley (kN)	Ultimate Compression Resistance, PDA (kN)	% of Error-Hiley to PDA Capacity
Parameter	Berminghammer		
Number of Points	205		
Average	5156	2578	-105
Max	9571	4400	48
Min	756	623	-419
R^2	0.29		--
Parameter	Delmag		
Number of Points	46		
Average	2715	2039	-41
Max	4770	4200	17
Min	745	600	-112
R^2	0.7		--
Parameter	Pileco		
Number of Points	18		
Average	3454	3003	-16
Max	4888	4500	24
Min	1500	1500	-44
R^2	0.56		--
Parameter	APE		
Number of Points	1		
Average	3989	6600	40
Max	3989	6600	40
Min	3989	6600	40
R^2	---		--

Table 73 - Summary of the load ratio results of Hiley to PDA based on diesel hammer specification

	Load Ratio (Hiley/Static)			
Parameter	Berminghammer	Delmag	Pileco	APE
No. of Points	205	46	18	1
Average	2.05	1.41	1.16	0.6
Std Dev, σ	0.67	0.32	0.2	---
COV (%)	33	23	17	---
Max	5.19	2.12	1.44	0.6
Min	0.52	0.83	0.76	0.6



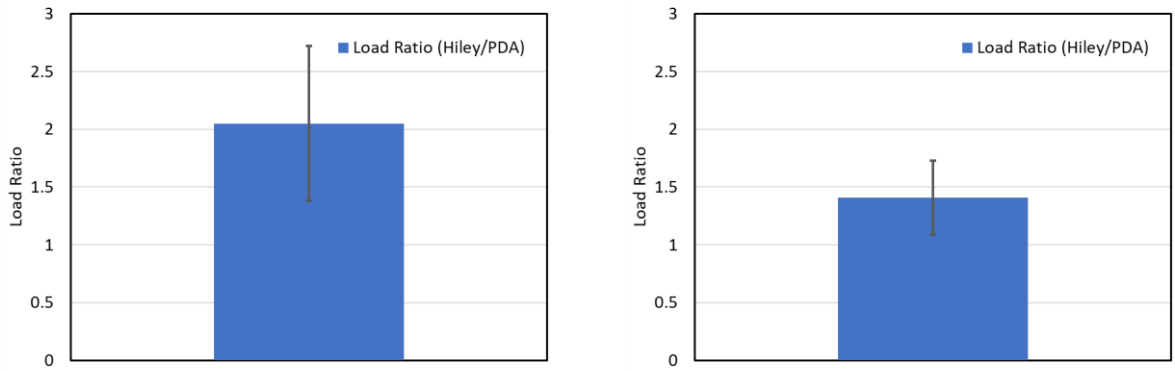
a) Berminghammer

b) Delmag

c) Pileco

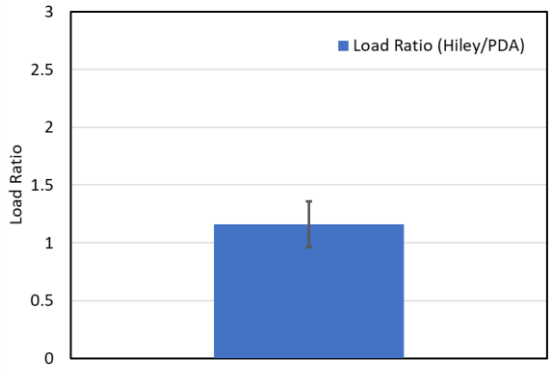
d) APE

Figure 111 - PDA, pile capacity vs. Hiley, pile capacity based on diesel hammer specification

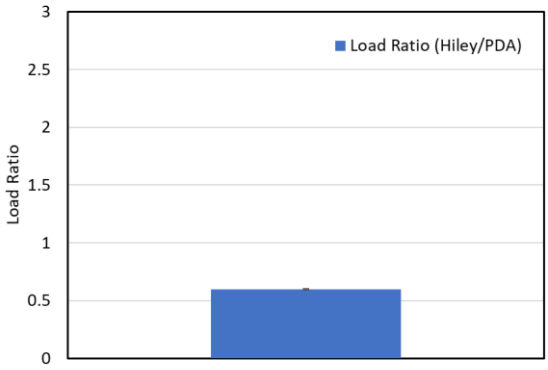


a) Berminghammer

b) Delmag



c) Pileco



d) APE

Figure 112 - Hiley to PDA Load ratio based on diesel hammer specification

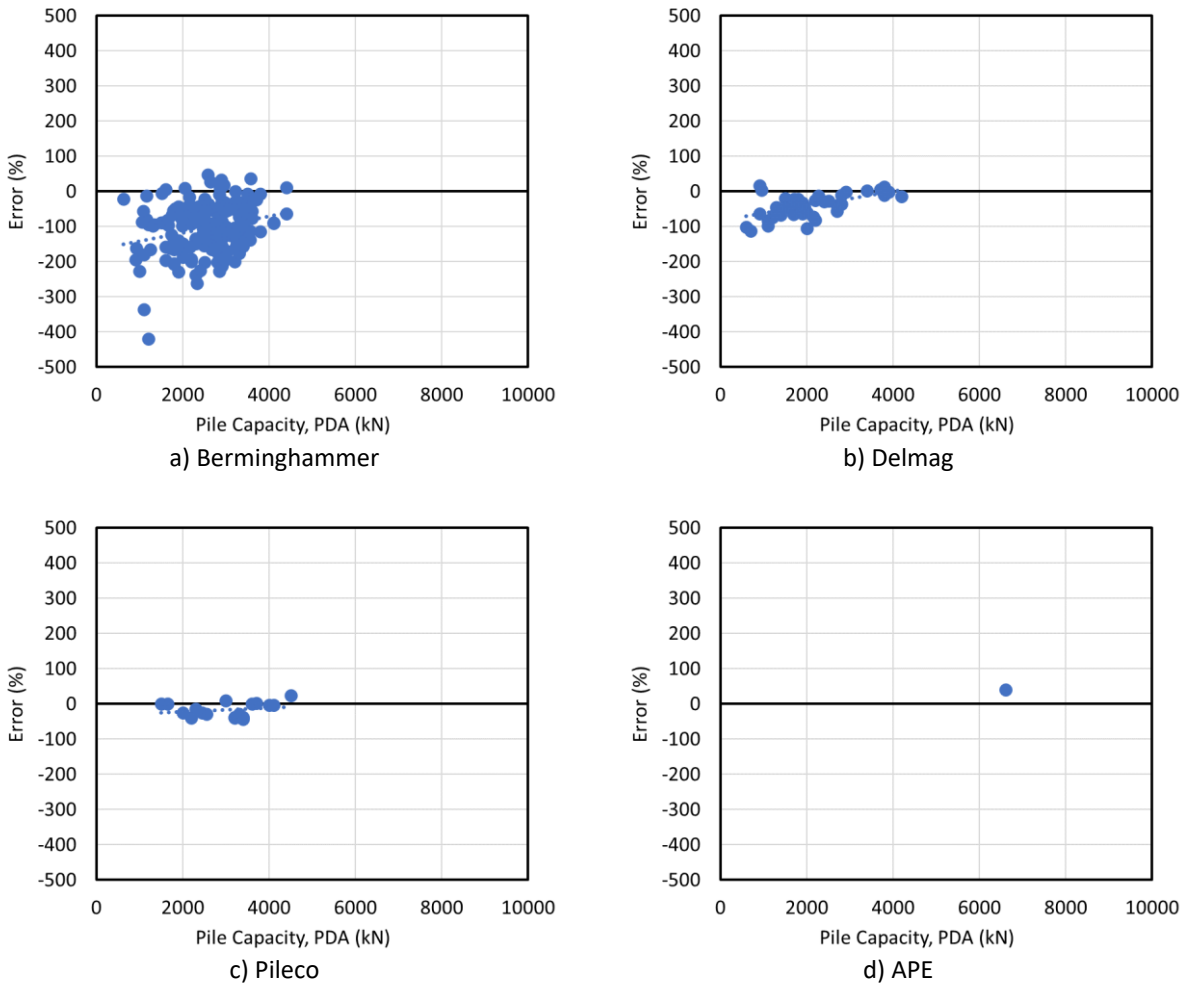


Figure 113 - Percentage of error of Hiley to PDA, pile capacity vs. PDA, pile capacity based on diesel hammer specification

7. Discussion of Results

A statistical analysis was performed on the data gathered from 34 sites around Ontario. Three different analyses were completed making the following comparisons:

1. Hiley and PDA tests vs. Static Pile Load Tests (where available)
2. Hiley and PDA tests vs. Ultimate Resistance as per FIDR's
3. Hiley vs. PDA test

7.1 All Data

Considering all available data points compared simultaneously without filtering for any parameters, PDA tests overall provide a better estimation of the ultimate capacity compared to Hiley tests when considering their correlation with the pile resistance obtained from static pile load tests and the ultimate geotechnical resistance provided in the FIDRs. PDA tests showed less variation in the data and a lower percentage of error while a wider scatter of datapoints was observed with Hiley test results, with a higher variation in the data and percentage of error. Based on the above analyses, PDA tests were selected as the benchmark for the comparison between PDA tests and Hiley tests performed on the same pile since it was in general the more accurate and reliable testing method.

A comparison between Hiley and PDA tests showed that Hiley tests almost doubled the estimated pile resistance measured on site for the same pile when compared to PDA. The datapoints, while scattered, generally followed the 1:2 line (i.e., the line where Hiley resistance was double PDA resistance). It is also observed that as the pile resistance increases, the relative amount by which Hiley tests overestimates the PDA test value increases as well indicating that the two tests better correlate for lower resistance piles.

A discussion of all the parameters analyzed separately is provided in following sections below.

7.2 Subsurface Conditions and Load Transfer Mechanism

For end bearing piles in bedrock, there were no static pile load tests available. When comparing Hiley and PDA results to the ULS geotechnical resistances provided in FIDR's, no correlation was found; a large amount of scatter was observed in the data points for both testing methods. However, PDA tests are likely to be conservative when estimating the piles capacity (the points generally fell above the 1:1 line) while Hiley tests are very likely to overestimate the ULS geotechnical resistance provided in FIDRs. When comparing PDA tests directly to Hiley tests, a large amount of scatter is observed in the data indicating low correlation between PDA and Hiley. In general, Hiley tests provided an estimated pile resistance that is close to double of that estimated by PDA tests.

For friction piles driven through cohesionless soils, Hiley tests were slightly closer to the pile capacity measured in the field based on static pile load tests. However, the number of data points is limited, and therefore caution should be used when comparing the data. Hiley tests results showed a better match than PDA tests in terms of the average measured resistance compared to the FIDR ULS geotechnical resistance, with Hiley tests on average matching much closer to the FIDR values while PDA tests on average is closer to 50% of FIDR value. The variation in the data is marginally less for PDA tests, indicating that either tests produce a similar level or variability in their estimates. It should be noted that values obtained from the FIDR are not the actual ultimate resistance of piles but rather an estimate based on static formulae. The actual developed capacities of the pile(s) may differ from the estimated value as presented in the FIDR. When comparing the Hiley tests directly to the PDA tests, it was observed that Hiley tests estimated a resistance that was 70% higher on average than PDA tests. However, given that the PDA load consistently underestimated the FIDR ULS resistance load by closer to 50%, Hiley appears to better estimate the pile's resistance, at least in terms of the value provided in the FIDRs. The static tests piles load tests provided some validity to this observation as Hiley tests were slightly closer to the field measurement, although as mentioned above, this is a small data set and caution should be used in this interpretation. It should be noted that this observation is not linked to any other parameters.

For the remaining cases (end bearing piles in cohesionless and cohesive soils and friction piles in layered and cohesive soils), PDA testing outperformed Hiley tests both in terms of its comparison with static pile load tests (although only tests for end bearing piles in cohesionless soils and friction piles in layered soils are available) and with the ULS geotechnical resistance provided in the FIDRs. The average pile resistance estimated from PDA tests were much closer and had considerably less variation in the data points when compared to Hiley tests. On average, PDA tests appear to be somewhat conservative while Hiley tests consistently overestimate the pile's resistance by a large factor. When comparing Hiley tests directly to PDA tests, Hiley tests again show a much higher resistance than PDA tests for the same piles.

7.3 Pile Inclination

The analysis for performance of PDA and Hiley tests individually had to be made on the basis of its comparison with the FIDR ULS geotechnical resistance since all pile static load tests were done on vertical piles. PDA testing provided a much better comparison to the FIDR ULS geotechnical resistance for both vertical and battered piles in terms of the average resistance. However, there appears to be less variation in the relationship for vertical piles where the datapoints for battered piles are much more scattered. However, ignoring outlier points, the variation in the PDA testing is significantly reduced. Therefore, for both vertical and battered piles, PDA testing outperforms Hiley tests. Hiley tests consistently overestimated the pile's capacity in terms of its comparison to the FIDR ULS resistance (approximately 1.5 times), with a similar distribution of data points and high level of variation for both vertical and battered piles.

When comparing PDA tests directly to Hiley tests, Hiley tests on average provided a much higher estimate of the pile's resistance. However, little difference was observed between vertical and battered piles.

7.4 Pile Type and Size

In general, PDA testing provided a much better estimation of a pile's resistance than Hiley testing when compared to static pile load tests for all pile types. In all cases for PDA, the relationship was relatively close to the 1:1 line with lower amounts of variation in the data. It should be noted that the data set is limited for precast piles, pipe piles, and timber piles, and more variation may occur with an increase in tests.

Similarly, when compared to the FIDR ULS geotechnical resistances, PDA testing provided on average a closer estimate to this value with much less variation in the data. However, it should be noted that HP310 x 79 piles were excluded from this specific analysis as the FIDR only provided ULS resistances for pipe piles with no provision of substituting pipe piles with H-Piles. However, for the other sizes, the relationship is similar and therefore likely to be the same for HP310 x 79 piles. In terms of its comparison with the FIDR resistance, pipe piles seemed to have the best correlation, however there is a low sample size of tests performed on pipe piles and therefore caution should be used when drawing any conclusions.

When comparing PDA tests directly to Hiley tests, it was observed that the Hiley tests results were much higher than PDA for H-Piles and Timber piles, moderately higher for precast concrete piles, and slightly lower for pipe piles. However, as noted above, the data set is limited for precast piles, pipe piles, and timber piles. When comparing the different sizes of H-Piles, no significant differences were observed in the correlation between PDA and Hiley tests.

7.5 Pile Embedment Length

PDA tests provide a much better estimation of the pile's resistance in terms of its comparison with static pile load tests. Also, there is no significant difference observed in the PDA tests performance in terms of different pile embedment lengths. The variation of data points for Hiley tests is very high for all pile lengths and Hiley tests may greatly overestimate or underestimate the pile's actual resistance.

PDA tests provide a much better estimation of the pile's resistance in terms of its comparison with the FIDR ULS geotechnical resistance. No significant differences were noted for the different pile lengths. The data points appear to be closer to unity for piles over 36 m; however, this may be a coincidence due to a lack of data points compared to the other lengths. When comparing the Hiley test results with the FIDR ULS geotechnical resistance, a trend is observed where the Hiley tests performs better with

an increase in pile embedment length. However, the load is still overestimated for all cases with higher levels of variation in the data compared to PDA testing PDA tests provided a much better estimation of the pile's resistance both in terms of its comparison with static pile load tests and with the FIDR ULS geotechnical resistance.

When comparing PDA tests directly to Hiley tests, no significant differences were observed for different pile lengths. For all cases, Hiley provided a higher estimate of a pile's developed capacity compared to PDA.

7.6 Pile Splice

When looking at the correlation with the pile resistance obtained from static pile load tests. PDA testing provides a much better estimation for both piles which have been spliced and those which have not. The variation in the data is also lower for PDA tests. A somewhat better correlation is observed for PDA tests when compared to static pile load tests for piles which have not been spliced. However, the data set for this parameter is relatively small, and the data points may have a similar distribution to spliced piles if the data set were to be increased.

Comparing the correlations with the ultimate geotechnical resistance provided in the FIDRs, PDA testing also provides a much better estimation for both piles which have been spliced and those which have not. However, for both PDA and Hiley tests, no significant differences were observed for spliced and non-spliced piles.

When comparing PDA tests directly to Hiley tests, Hiley tests on average provided a much higher estimate of the pile's resistance. However, little difference is observed between spliced piles and piles which have not been spliced.

7.7 Pile Driving Event

There were no observed differences in the performance of Hiley tests and PDA tests between different driving events when compared to static load tests, FIDR ultimate resistances, and direct comparisons between Hiley and PDA. In general, PDA testing outperformed Hiley tests for all three driving events. Based on static pile load tests, end of restrike (EOR) appear to have a good correlation for PDA tests, however the sample size is very limited, and the distribution of data points is likely to be similar with an increase in the number of tests.

7.8 Hammer System

When comparing PDA tests and Hiley tests to the static pile load tests, PDA testing performed with diesel hammers provided a much better estimate of the pile's resistance compared to Hiley tests, with a lower amount of variation in the data. Based on the single hydraulic hammer test, both PDA and Hiley tests underestimated the capacity of the pile. However, no conclusion can be made from one data point. There were no static pile load tests done at sites where drop hammers were used.

When comparing PDA and Hiley tests to the FIDR ULS geotechnical resistances, PDA tests performed with diesel hammers provided on average a better estimation of the pile's resistance with a lower level of variation in the data compared to Hiley tests. For drop hammers, both PDA and Hiley tests slightly underestimated the pile's resistance; however, in general there is good agreement between these tests and the FIDR ULS resistance. However, the data set is only limited to two sites with a relatively small sample size. It should be noted that drop hammers were only used for end bearing piles in cohesionless and cohesive soils with hammer energy of 80 kJ. Hydraulic hammers were excluded from this analysis as only one test was available.

When comparing PDA tests directly to Hiley tests, the correlation showed excellent agreement for drop hammers indicating that both tests could be used with similar accuracy. However as mentioned above, the data set is limited. As reflected in the other analyses', Hiley tests on average provided a much higher estimate of a pile's developed capacity than PDA tests.

7.9 Pile Cushion

When comparing PDA tests and Hiley tests to the static pile load tests, PDA testing is observed to perform better when driven with a cushion. However, due to the small sample size, the difference between using a cushion and not may be due to chance and an increase in tests may yield a similar distribution in data for both cases. When comparing PDA to Hiley tests, PDA testing

on average provided a better estimation of the pile's resistance with a lower level of variation in the data compared to Hiley tests.

The FIDRs' only provided ULS geotechnical resistances for steel piles. All steel H-Piles driven via diesel hammer analyzed in this study were driven without a cushion, while all piles driven via drop hammer were driven with a cushion. Therefore, no evaluation could be made of the effect of driving with a pile cushion on the PDA/Hiley resistance estimate.

When comparing PDA tests directly to Hiley tests, there is a good correlation between the tests for piles driven with a cushion. It should be noted that about half the tests in this data set were performed with a drop hammer which was observed to perform well for both PDA and Hiley tests. However, the piles tested with a diesel hammer also provided good correlation. However, the data set is relatively small, and the correlation may become more variable with an increase in tests.

7.10 Pile Shoe/Bearing Point

When comparing PDA tests and Hiley tests to the static pile load tests, PDA tests provided a better estimate of the pile's resistance compared to Hiley tests, with a lower amount of variation in the data for both piles driven with and without a pile shoe/bearing point. PDA tests appear to perform better for piles driven without a shoe, however the sample size is very limited, and it's possible the distribution of data points would become similar with an increase in the number of tests.

When comparing PDA and Hiley tests to the FIDR ULS geotechnical resistance, only two piles were driven without a driving shoe/bearing point, therefore an evaluation could not be made on the effect of driving shoes on the estimated capacity from Hiley and PDA tests.

When comparing PDA tests directly to Hiley tests, no difference was observed in piles driven with and without a pile shoe/bearing point.

7.11 Hammer Rated Energy

When comparing PDA and Hiley tests to the FIDR ULS geotechnical resistance, PDA tests also performed better than Hiley tests for all rated hammer energies. The average resistance estimated by PDA testing and the level of variance in the data improved for hammers with rated energies greater than 90 kJ. This may suggest that high energy hammers produce slightly more accurate and reliable results for PDA tests, however this difference was not observed in the comparison with static pile load tests. The accuracy of the Hiley test appears to decrease with increasing hammer energy, however the decreasing level of variance in the data points suggests that the values become more consistent with increased energy.

When comparing PDA tests directly to Hiley tests, the average Hiley test value increases with increasing hammer energy. However, for all cases, Hiley tests provided a higher estimate of the pile's resistance compared to PDA tests.

7.12 Pile Driving Resistance

For the purpose of this study, low driving resistance is considered less than 2 blows per 25 mm, high driving resistance is considered 8 blows per 25 mm, and intermediate resistance is considered between and equal to these values.

A comparison of driving resistances using piles subjected to static load tests was not performed due to a lack of data points available for low and intermediate driving resistances. When comparing PDA and Hiley tests to the FIDR ULS geotechnical resistances, PDA tests performed at high and intermediate driving resistances provided on average a better estimation of the pile's resistance with a lower level of variation in the data compared to Hiley tests. For low driving resistances, Hiley tests outperformed PDA tests both in terms of estimating capacity and level of variance of data. On average, the resistance measured by Hiley tests was equal to the FIDR value while PDA tests were closer to half. However, these data points are limited to end bearing piles driven into cohesionless and cohesive soils. It should also be noted that the data set is relatively small, and the variance may increase with an increase in the number of tests.

When comparing PDA tests directly to Hiley tests, Hiley tends to provide a higher estimation of the pile resistance for all three levels of driving resistance. For high and intermediate levels of driving resistance, PDA testing is better suited in terms of how it

compared to the FIDR ULS load. For low driving resistances, even though Hiley tests are closer to double to that of PDA tests, given that PDA testing estimates are closer to half of the FIDR load, these factors may cancel out and Hiley tests may be better suited during low driving resistance events. It should be noted however that the FIDR estimate is best on static formula which are approximate and not a true measurement of the pile's geotechnical resistance.

7.13 Diesel Hammer Specification

A comparison of diesel hammer specification using piles subjected to static load tests was not performed due to a lack of data points available. When comparing PDA and Hiley tests to the FIDR ULS geotechnical resistance, PDA tests performed with Berminghammer diesel hammers provided on average a better estimation of the pile's resistance with a lower level of variation in the data compared to Hiley tests. For Delmag hammers, PDA and Hiley tests performed similarly except PDA tests slightly underestimating the pile resistance on average (by 12%) and Hiley tests slightly overestimating the pile resistance (by 11%). Hiley tests showed slightly less variance in the datapoints although the difference is small enough that they can be considered equivalent. For Pileco hammers, both PDA and Hiley tests overestimated the pile resistance based on the FIDR ULS load. However, PDA tests were slightly more accurate with less variance in the data. It should be noted that the Pileco results were obtained from one site; therefore, no clear conclusion can be made. No evaluation could be made on APE diesel hammers as only one test was performed.

When comparing PDA tests directly to Hiley tests, Hiley tests tend to provide a higher estimate of pile resistance compared to PDA tests. The worst case was observed in Berminghammer diesel hammers; the relationship was seen to slightly improve for Delmag hammers. Pileco hammers are much closer to a 1:1 relationship, with Hiley tests on average only slightly overestimating the pile resistance compared to PDA. However, as noted above, Pileco results were obtained from one site and therefore no clear conclusion can be made.

8. Conclusions and Recommendations

Assessments of the relative performance of the PDA and the MTO Modified Hiley Formula in the control of piling installation of some MTO and EXP projects, have been completed as part of this study. Details of the methodology, relationships examined, and results have been presented in text and figures, in the body of this report. Table 74 summarizes key elements of the findings. Table 75 summarizes the advantages, disadvantages, cost, risks, and consequences of static load test, Hiley test, PDA test along with CAPWAP analysis.

Table 74 - Summary of Best Match Method of Pile Control and Observed Trends

No	Parameter	Sub - Parameter	Best Match Method According to:		Hiley to PDA	Comments
			Static	FIDR		
1	All Data	---	PDA	PDA	Not Matching (overestimate)	
2	Subsurface Conditions and Load Transfer Mechanism	End bearing – Bedrock	NA	PDA	Not Matching (overestimate)	1. There is no correlation for either PDA or Hiley tests to the ULS geotechnical resistance provided in their respective FIDRs. However, PDA tests are likely to be conservative when estimating the piles capacity while Hiley tests are very likely to overestimate the ULS geotechnical resistance provided in FIDRs.
		End bearing – Cohesionless	PDA	PDA	Not Matching (overestimate)	
		End Bearing Piles – Cohesive	NA	PDA	Not Matching (overestimate)	
		Friction Piles – Layered	PDA	PDA	Not Matching (overestimate)	
		Friction Piles – Cohesionless	PDA and Hiley	Hiley	Not Matching (overestimate)	1. PDA also provide close results compared to static test. Sample size based on limited data (2-points). 2. Hiley tests results showed a better match than PDA tests in terms of the average measured resistance compared to the FIDR ULS geotechnical resistance, while PDA tests on average is closer to 50% the FIDR value.
		Friction Piles – Cohesive	NA	PDA	Not Matching (overestimate)	
3	Pile inclination	Vertical Piles	NA	PDA	Not Matching (overestimate)	1. PDA testing provided a much better comparison to the FIDR ULS geotechnical resistance for both vertical and battered piles in terms of the average resistance. 2. There appears to be less variation in the relationship for vertical piles where the datapoints for battered piles are much more scattered. However, ignoring outlier points, the variation in the PDA testing is significantly reduced.
		Battered Piles	NA	PDA	Not Matching (overestimate)	

No	Parameter	Sub - Parameter	Best Match Method According to:		Hiley to PDA	Comments
			Static	FIDR		
4	Pile Type	H-Piles	PDA	PDA	Not Matching (overestimate)	
		Pipe Piles	PDA	PDA	Not Matching (underestimate)	1. Sample size based on limited data (3-points) for static tests.
		Precast Concrete Piles	PDA	NA	Not Matching (overestimate)	1. Sample size based on limited data (3-points) for static tests.
		Timber Piles	PDA	NA	Not Matching (overestimate)	1. Sample size based on limited data (2-points) for static tests.
5	Pile Embedment Length	L ≤ 12 m	PDA	PDA	Not Matching (overestimate)	1. PDA tests provide a much better estimation of the pile's resistance both in terms of its comparison with static pile load tests and with the FIDR ULS geotechnical resistance.
		12 m < L ≤ 24 m	PDA	PDA	Not Matching (overestimate)	
		24 m < L ≤ 36 m	PDA	PDA	Not Matching (overestimate)	
		36 m < L ≤ 60 m	PDA	PDA	Not Matching (overestimate)	
6	Pile Splice	With Splice	PDA	PDA	Not Matching (overestimate)	
		Without Splice	PDA	PDA	Not Matching (overestimate)	
7	Pile Driving Event	EOID	PDA	PDA	Not Matching (overestimate)	1. PDA testing in general outperformed Hiley tests for all three driving events based on pile load test sand FIDR ULS geotechnical resistance. However, the variation in data in case of EOR is higher. Data for EOR assessment is limited.
		BOR	PDA	PDA	Not Matching (overestimate)	
		EOR	PDA	PDA	Not Matching (overestimate)	
8	Hammer System	Diesel Hammer	PDA	PDA	Not Matching (overestimate)	
		Drop Hammer	NA	PDA and Hiley	Matching	1. It should be noted that drop hammers were only used for end bearing piles in cohesionless and cohesive soils. 2. Based on limited data for hammer energy of 80 kJ.

No	Parameter	Sub - Parameter	Best Match Method According to:		Hiley to PDA	Comments
			Static	FIDR		
9	Pile Cushion	With Cushion	PDA	PDA and Hiley	Matching	1. Hiley tests also provide good estimation for static capacity with a higher variation in the data based on assessment with cushion. 2. Limited data available for the comparison between Hiley and PDA vs. FIDR ULS geotechnical capacity based on assessment with cushion.
		Without Cushion	PDA	PDA	Not Matching (overestimate)	
10	Pile Driving Shoe/Bearing Point	With Driving Shoe/Bearing Point	PDA	PDA	Not Matching (overestimate)	
		Without Driving Shoe/Bearing Point	PDA	NA	Not Matching (overestimate)	
11	Hammer Rated Energy	30 kJ < E ≤ 60 kJ	PDA	PDA	Not Matching (overestimate)	
		60 kJ < E ≤ 90 kJ	PDA	PDA	Not Matching (overestimate)	
		E> 90 kJ	PDA	PDA	Not Matching (overestimate)	
12	Driving Resistance	High	NA	PDA	Not Matching (overestimate)	
		Intermediate	NA	PDA	Not Matching (overestimate)	
		Low	NA	Hiley	Not Matching (overestimate)	1. Limited data available for the comparison between Hiley and PDA vs. FIDR ULS geotechnical capacity. 2. These data points are limited to end bearing piles driven into cohesionless and cohesive soils.
13	Diesel Hammer Specification	Berminghammer	NA	PDA	Not Matching (overestimate)	
		Delmag	NA	Hiley and PDA	Not Matching (overestimate)	1. For Delmag hammers, PDA and Hiley tests performed similarly except PDA tests slightly underestimates the pile resistance in terms of FIDR.
		Pileco	NA	NA	NA	
		APE	NA	NA	NA	

Table 75 - Advantages, Disadvantages, Costs, Risks and Consequences

Comparison	Static	Hiley	PDA along with CAPWAP
Advantages	- Relatively accurate in determining ultimate capacity and settlement of piles in comparison to other tests - Can be performed on all soil types	- Relatively easy - Time saving (fastest test to administer) - Less expensive than Static load and PDA tests - Appropriate for cohesionless soils	- Relatively easy - Test can be performed faster in comparison to SPLT - Less expensive than static load test - Less site space is required to set up test in comparison to SPLT - Appropriate for most of the soils - Can be used to optimize the foundation, pile type, and size - CAPWAP can be used in conjunction with PDA to provide shaft and toe capacities - Can monitor driving stresses and hammer performance - Can assess pile integrity - Can provide real time feedback of pile stresses due to impact of hammer and soil resistance during driving - In most cases, it provides results closer to the SPLT
Disadvantages	- Most costly test - Most time-consuming test -Adequate space required to execute test (not practical for sites with limited space) -Test piles may have to be installed away from foundation footprint, providing geotechnical resistance under slightly different conditions.	- Hiley formula comprises of several constants, some of which are based on engineering judgement - Does not consider the actual energy transferred to the piles - Potential for estimated capacity to be incorrect due to use of wrong value(s) of constant(s) in formula (e.g., wrong value for coefficient of restitution, “e”) - Results are less accurate than both SPLT and PDA (It generally overestimates)	- More expensive than Hiley test - Results are less accurate than those from SPLT - Noise and vibration may be disturbing to surrounding people and properties during test

Comparison	Static	Hiley	PDA along with CAPWAP
		- Issues with reproducibility and repeatability - Noise and vibration may be disturbing to surrounding people and properties during test	
Risks	- Load cell and LVDTs must be well installed, and calibrated.	- Less conservative in estimating pile capacities in comparison to both SPLT and PDA - Pencil and record sheet must be well installed	- Sensors must be well installed, and calibrated
Consequences	- Inaccurate data output leading to wrong pile capacity estimation	- Overloading of piles more likely to occur due to overestimation of capacities - Inaccurate data output leading to wrong pile capacity estimation	- Inaccurate data output leading to wrong pile capacity estimation

The following additional observations and conclusions can be made:

- The MTO Modified Hiley Formula is cheap and simple to perform but cannot be generally relied upon to predict a pile's ultimate capacity with a reasonable degree of accuracy and repeatability in most cases. The analysis of the data set indicates wide scatter in the results and a non-conservative trend to overprediction in many cases. The MTO Hiley Formula, when used in specific local areas and particular cases by competent individuals, can provide reasonable results that serve to enhance engineering judgement. The approach is convenient; however, it is fundamentally incorrect. Most formulae only consider the kinetic energy of the driving system. The variability of equipment performance is typically not considered. Second, the soil resistance is very crudely treated by assuming that it is a constant force. Third, the pile is assumed to be rigid, and its length is not considered. This assumption completely neglects the pile's flexibility, which affects its ability to penetrate the soil.
- Both the Canadian Standard Association (CSA) in the Canadian Highway Bridge Design Code (CHBDC) (2019) and the Canadian Geotechnical Society (CGS) in the Canadian Foundation Engineering Manual (CFEM) (2006) do not recommend using Dynamic Pile Driving Formulae in Designs. It is worth mentioning that neither of these standards assigns a resistance factor for results obtained from dynamic formulae. In this regard, resistance factors in LFRD should not be viewed as a direct replacement/conversion from/for the factor of safety (FOS) used in the working stress design. Resistance factor is a statistically based multiplier applied to the resistance determined from a specific analysis method or procedure. It may be a value determined by national/provincial code/practice, or it may be a locally calibrated value determined from past practice, databases, and correlation studies. Load factors are applied to address the uncertainty on the load side. Both the load and resistance factors are tied to a target reliability index, β, which quantifies the probability of non-performance or failure. However, it would be a logical deduction and in relative terms, that if a particular method is associated with a higher FOS, then the expectation would be that the resistance factor would have a relatively lower value. To achieve goals of more economic designs using the Load and Resistance Factor Design (LRFD), while maintaining the required levels of safety, the accuracy of monitoring tools is of higher import.
- MTO Modified Hiley Formula as documented on Dwg SS103-11 (MTO 2016) states "When applying the Hiley formula, the hammer should be operated at full capacity". If the hammer is not operating at full capacity, i.e., ~35-37 blows per minute, depending on the hammer, the height of stroke should be calculated to determine the actual hammer potential energy if and where the Hiley formula is still to be used.
- The reliability of the estimation of the capacity of piles using PDA with an experienced and skilled operator is close to that of a routine static load test for most conditions examined noting the complication of time dependency. Signal matching (CAPWAP) analysis must be carried out when undertaking PDA testing to improve effectiveness. The PDA testing shall be carried out by a company registered and approved in MTO's RAQs as the Specialty: Geotechnical (Structures and Embankments - Medium or High Complexity). PDA tests shall be performed by an Engineer/Technician with at least 5 years of experience in high-strain dynamic testing who will be under the direct supervision of an Engineer with at least 10 years of experience in high-strain dynamic testing.
- For piles driven in soils having time-dependent features (soil set-up and relaxation), the accuracy of dynamic techniques for calculating pile capacity is crucial. Because the static loading test only produces the pile capacity during the moment of test, it cannot be recognized as a unique standard for determining pile capacity. This is particularly important where static load tests are conducted at relatively short intervals after initial pile driving. This issue is also a restriction of dynamic capacity testing noting the complex relationship of the change in soil strength and soil-pile adhesion after initial driving with the dynamic testing approach. It is important to consider the time factor for the correct assessment of the reliability of dynamic testing (Svinkin and Woods 2017). Any comparison between static and dynamic tests should be done for tests that were carried out within a brief period (2 days for example).
- The terms "soil set-up" and "soil relaxation" describe, respectively, the time-dependent increase and decrease in the capacity "nominal resistance" of driven piles. In case of soil set-up, the capacity of driven piles increases with time following pile driving. Set-up was observed in piles driven into saturated clays, loose to medium-density silts, or fine sands. In these soils, excess (positive) pore pressures are developed from soil compressibility and disturbance. These excessive pore pressures are caused by a combination of radial compression when the soil is displaced by the pile and

soil shearing and remolding. Both the effective stresses acting on the pile and the soil shear strength are decreased by the excessive pore pressures. As a result, there is less pile capacity both while driving and for some time after. After driving, the pore water will flow radially away from the pile, releasing the excess pore pressures (Randolph et al. 1979). The soil reconsolidates and gains shear strength as excess pore pressures dissipates (FHWA 2016). Soil set-up might increase the loads on the piles. These loads are known as residual loads "locked-in loads", which are associated with the development of negative skin friction along the upper part of the piles and are resisted by the positive skin friction at both the lower part of the pile and toe resistance. The residual load due to pile "set-up" might increase after the dissipation of excess pore water pressure from soil recovery from the disturbance that occurred during pile driving. The main problem that occurs when the residual load is not considered when evaluating the results of a pile loading test is that the shaft resistance appears to be higher than it actually is, and the toe resistance appears to be proportionally lower (Fellenius 2002). Dynamic monitoring (CAPWAP) is especially suited to instantly assessing the capacity at the end of driving since it collects data while driving. Restrike testing can be conducted multiple times at different times following initial driving. On the basis of end-of-drive and restrike data, CAPWAP analysis may be used to determine the actual distribution of load between the shaft and toe (Komurka et al. 2003). To sum up, PDA along with CAPWAP can be used to predict a piles capacity and measure the residual loads. In the case of soil relaxation, the capacity of driven piles decreases with time following pile driving. Relaxation was observed in piles driven into dense saturated fine sands, dense (non-cohesive) silts, or weak laminated rocks such as shale. In these soils, negative pore pressures are developed because of soil dilatation (an increase in the volume) near the pile toe after the driving. Consequently, the effective stress and thus the pile resistance are temporarily increased. After time, the developed negative pore water pressures dissipate leading to a decrease in the effective stress and thus the pile resistance.

- There is potential for negative skin friction “drag force” in piles driven into soft clay. Utilizing CAPWAP from the data obtained from the Pile Driving Analyzer can be used to determine both shaft and toe resistances, which can be used to back-calculate the strength parameters at the shaft and Toe or β-coefficient and Nq value. These values can be implemented in the unified design method to determine the drag force and location of neutral plane.
- Piles driven into dense to some very dense sands and softer rock (shales/limestones) can have a significant loss in toe resistance over time. The data sets indicate that overdriving is beneficial to limit the detrimental effects of relaxation; driving to a capacity more than the required ultimate capacity is recommended when piles are terminated in relaxation prone materials. Driving criteria should not be established that require excessive amounts of driving beyond refusal driving conditions. Practical refusal is typically defined as 20 blows per 25 mm of penetration (20 blows per inch) with the hammer operated at its maximum fuel or energy setting, or at a reduced fuel or energy setting recommended by the Engineer based on pile installation stress control. In no case should driving continue for more than 75 mm (3 inches) at practical refusal driving conditions. Depending on the end bearing material and pile type, most of the data presented herein and from the literature suggests that driving to an ultimate capacity that includes a 20 to 40% loss in toe resistance would compensate for the relaxation magnitude in about 80% of the database cases.
- CAPWAP can be used in conjunction with PDA to provide real time feedback of pile stresses due to impact of hammer and soil resistance during driving. The information can be used to assess the state of the pile during driving, which can aid in judgment to prevent pile damage.
- Based on the results of this study, PDA predicted results tend to marginally underestimate the geotechnical capacity in most cases. Static load tests are usually completed well after the initial driving of piles. This allows more time relative to restrike with the PDA for the pile to gain capacity in cases where “set-up’ occurs (in some cases, waiting a week for PDA testing as opposed to 6 weeks for the SLT; this can be significant). As such, the correlation between the static load test and PDA would be impacted with the PDA expected to underestimate (the Essa Road project in Barrie is an example of this phenomenon). Soil set up can be verified by Dynamic measurements with the PDA during restriking or by static load test on larger projects, noting that the actual delay between End of Initial Drive (EOID) and restrike can influence the measured capacity. On the other hand, if the setting is one within which relaxation is the issue, the measured value from the SLT would be relatively lower.
- It is important to consider serviceability/acceptable settlement issues.

The findings are consistent with those of many previous studies reported in the literature. Specifically, it can be concluded that the use of Dynamic Pile Driving Formulae and for this study (the MTO modified Hiley) notwithstanding the numerous attempts to refine them, cannot be generally relied upon to predict a pile's ultimate capacity with a reasonable degree of accuracy and repeatability. The MTO Hiley Formula (and similar Dynamic Pile Driving Formulae) can be close to the real value of static capacity of the pile in specific local areas and particular cases (friction piles in cohesionless soils) when used in these settings and by competent individuals they can serve to enhance engineering judgement. In other cases [steel piles driven by drop hammer (based on limited data for hammer energy of 80 kJ), and for piles driven with Delmag diesel hammers], Hiley results are close to the PDA results; this can serve to enhance engineering judgement. However, the argument that there is a continued "practical" need for Dynamic Formulae is now less convincing since the wave equation analysis is easy to perform and is fundamentally correct; dynamic monitoring with the PDA is well established and has been in the Canadian Market since the mid-1970s. There are available programs with the WEAP approach that:

- Simulates the pile response to pile driving equipment.
- Calculates soil resistance, dynamic pile stresses, and estimated capacities based on field observed blow counts, for a given hammer and pile system.
- Helps select appropriate hammer(s) and driving system with known piling, soil, and capacity requirements.
- Determines whether a pile will be overstressed at a certain penetration or if refusal will likely occur before a desired pile penetration is reached (drivability analysis).
- Estimates the total driving time. This pile simulation and analysis allows the user to investigate which hammer is likely to be sufficient and economical for a certain pile and soil condition prior to mobilizing the hammer to the job.
- When Wave Equation Analysis and Dynamic Monitoring is used instead of Dynamic Formulae, several codes and standards of practice allow a leaner foundation design, translating to a lower factor of safety or higher resistance factor.

The following strategy is advanced for consideration of implementation by MTO for future control of piling on provincial projects:

- Based on this assessment, a strategy for phased substitution of the MTO Modified Hiley Formula with the WEAP/PDA CAPWAP approach is proposed for most applications. Ease of use, economics, efficiency, accuracy, consistency, and reproducibility were the key factors which drove the development of the proposed strategy.
- Refining of the MTO Modified Hiley Formula, or conversion to another Dynamic Formula for piling installation control for possible improved application was not part of the mandate of this study; however, some comments on these items are provided for general guidance and future consideration.
- MTO, in the near term, takes a phased approach to implementation of replacement of the MTO Modified Hiley Dynamic Formula by a WEAP/PDA /CAPWAP program to control piling on all Ministry Projects.
- Static pile load testing in conjunction with the WEAP/PDA/CAPWAP assessment should be considered whenever possible, on larger projects in complex settings where economic advantages can be projected. Time dependent issues should be incorporated.
- For those cases and for the period within which the use of a Dynamic Formula would still be a net benefit to the Ministry, a program of corroborative monitoring using an alternate formula (such as Gates) in conjunction with the Hiley should be considered. Available studies suggest that further development/modification of the Hiley Formula is unlikely to yield improved outcomes.
- It is recommended that further wave equation assessments/Dynamic Monitoring in conjunction with Static Pile Load Testing be carried out to study the potential for long-term incremental increase of Geotechnical Axial Resistance with time to optimize use in the LRFD design approach currently embraced.

- It has been suggested using variable damping as a function of time can enhance the prediction of pile capacity in pre-driving wave equation analysis (Svinkin and Woods 2017). Consideration should be given to further field evaluation of this phenomenon.

9. Closure

The information presented in this report is based on the reports reviewed to provide information to support the development of a strategy for the successful implementation of the PDA as a partial or full substitution for the Hiley. The conclusions presented in this report reflects the results achieved at the time of this assignment. Details of the limitations of this report are presented as Appendix A, "Limitations and Use of Report".

We trust this report is satisfactory for your purposes. Should you have any questions, please do not hesitate to contact this office.

This Report was prepared by Stephen Fredericks, M.Eng., P.Eng., Daniel Mroz, M.E.Sc. E.I.T., Osama Drbe, PhD, E.I.T. It was reviewed by Silvana Micic, PhD, P.Eng., Tony Maini, P.Eng., Tae Kim, M.E.Sc., P.Eng. and Stan E. Gonsalves, M.Eng., P.Eng.

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Yours truly,
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Appendix A – Limitations and Use of Report

LIMITATIONS AND USE OF REPORT

BASIS OF REPORT

This report ("Report") is based on site conditions known or inferred by the geotechnical investigation undertaken as of the date of the Report. Should changes occur which potentially impact the geotechnical condition of the site, or if construction is implemented more than one year following the date of the Report, the recommendations of exp may require re-evaluation.

The Report is provided solely for the guidance of design engineers and on the assumption that the design will be in accordance with applicable codes and standards. Any changes in the design features which potentially impact the geotechnical analyses or issues concerning the geotechnical aspects of applicable codes and standards will necessitate a review of the design by exp. Additional field work and reporting may also be required.

Where applicable, recommended field services are the minimum necessary to ascertain that construction is being carried out in general conformity with building code guidelines, generally accepted practices and exp's recommendations. Any reduction in the level of services recommended will result in exp providing qualified opinions regarding the adequacy of the work. exp can assist design professionals or contractors retained by the Client to review applicable plans, drawings, and specifications as they relate to the Report or to conduct field reviews during construction.

Contractors contemplating work on the site are responsible for conducting an independent investigation and interpretation of the borehole results contained in the Report. The number of boreholes necessary to determine the localized underground conditions as they impact construction costs, techniques, sequencing, equipment and scheduling may be greater than those carried out for the purpose of the Report.

Classification and identification of soils, rocks, geological units, contaminant materials, building envelopment assessments, and engineering estimates are based on investigations performed in accordance with the standard of care set out below and require the exercise of judgment. As a result, even comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel may fail to locate some conditions. All investigations or building envelope descriptions involve an inherent risk that some conditions will not be detected. All documents or records summarizing investigations are based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated. Some conditions are subject to change over time. The Report presents the conditions at the sampled points at the time of sampling. Where special concerns exist, or the Client has special considerations or requirements, these should be disclosed to exp to allow for additional or special investigations to be undertaken not otherwise within the scope of investigation conducted for the purpose of the Report.

RELIANCE ON INFORMATION PROVIDED

The evaluation and conclusions contained in the Report are based on conditions in evidence at the time of site inspections and information provided to exp by the Client and others. The Report has been prepared for the specific site, development, building, design or building assessment objectives and purpose as communicated by the Client. exp has relied in good faith upon such representations, information and instructions and accepts no responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of any misstatements, omissions, misrepresentation or fraudulent acts of persons providing information. Unless specifically stated otherwise, the applicability and reliability of the findings, recommendations, suggestions or opinions expressed in the Report are only valid to the extent that there has been no material alteration to or variation from any of the information provided to exp.

STANDARD OF CARE

The Report has been prepared in a manner consistent with the degree of care and skill exercised by engineering consultants currently practicing under similar circumstances and locale. No other warranty, expressed or implied, is made. Unless specifically stated otherwise, the Report does not contain environmental consulting advice.

COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment form part of the Report. This material includes, but is not limited to, the terms of reference given to exp by its client ("Client"), communications between exp and the Client, other reports, proposals or documents prepared by exp for the Client in connection with the site described in the Report. In order to properly understand the suggestions, recommendations and opinions expressed in the Report, reference must be made to the Report in its entirety. exp is not responsible for use by any party of portions of the Report.

USE OF REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. No other party may use or rely upon the Report in whole or in part without the written consent of exp. Any use of the Report, or any portion of the Report, by a third party are the sole responsibility of such third party. exp is not responsible for damages suffered by any third party resulting from unauthorised use of the Report.

REPORT FORMAT

Where exp has submitted both electronic file and a hard copy of the Report, or any document forming part of the Report, only the signed and sealed hard copy shall be the original documents for record and working purposes. In the event of a dispute or discrepancy, the hard copy shall govern. Electronic files transmitted by exp have utilize specific software and hardware systems. exp makes no representation about the compatibility of these files with the Client's current or future software and hardware systems. Regardless of format, the documents described herein are exp's instruments of professional service and shall not be altered without the written consent of exp.

Appendix B– Summary of Sites

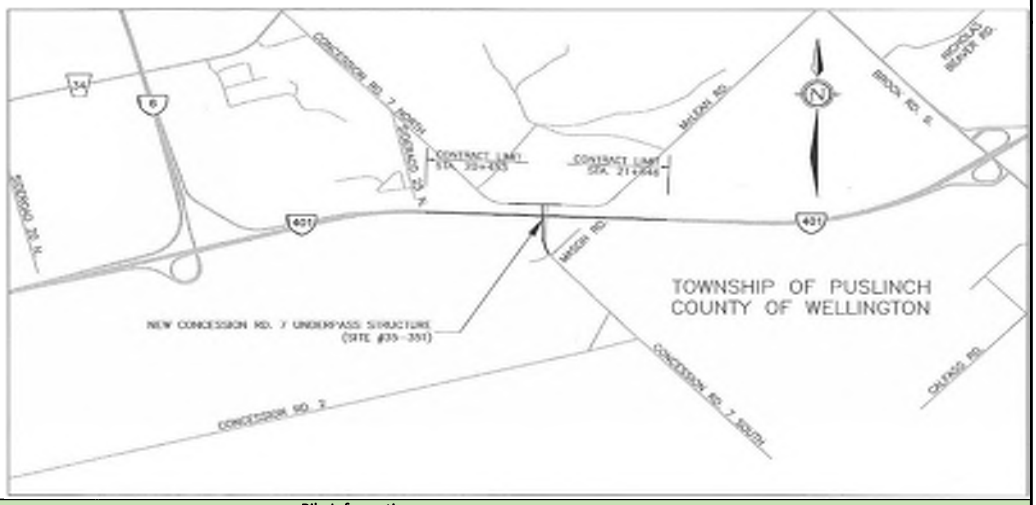
Site No:	1	Project:	Replacement of Underpass at H401 and Concession Road 7, Site No. 35-351

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

FIDR	Contract Drawings	Pile Load Test Report	PDA Report	Pile Logs
Replacement of Underpass at Highway 401 and Concession Road 7, Highway 401, Site No. 35-351, Station 21+042, Puslin h Township, County of Wellington, Latitude 43.44977; Longitude -80.15391, Agginment No. 3014-E-0014, GWP 3224-15-00	2018-3006	N.A.	Dynamic Testing of Piles, South Abutment, Concession Road 7 Underpass, Hwy. 401 and Hwy. 6 Realignment, June 27, 2019 Visit	Pile Driving Inspectionm MTO Contract 2018-3006, Replacement of Puslinch Twonship Bridge #11 (Concession Road 7 Underpass) over Highway 401 (Site #33-351), Puslinch (July 8, 2019) Townshio, Ontario

Pile I.D.	Soil Stratum	Pile Type
S1	Cohesionless	End Bearing
S3	Cohesionless	End Bearing
S9	Cohesionless	End Bearing

Pile	Event		
	Pile Installed	Hiley Test	PDA Test
S1	June 13-27, 2019	June 27, 2019	June 27, 2019
S3	June 24-27, 2019	June 27, 2019	June 27, 2019
S4	Jue 26-27, 2019	June 27, 2019	June 27, 2019



EOID: End of Initial Drive
BOR: Beginning of Restrike
Vert. Vertical Pile

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/Bearing Point	Splice Distance from bottom of pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
S9 (Vert.)	South Abutment	HP310 x 110	30.5	26.07	22.4	32.9	L-type Beams on Flanges at End	12.2/18.3	311.3	288.9
S1 (Vert.)	South Abutment		33.4	25.75	22	36.0		12.05/21.15	311.3	289.3
S3 (Vert.)	South Abutment		30.4	25.62	21.8	32.8		12.2/18.2	311.3	289.5

Hammer Specification

Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)
S9 (Vert.)	Delmag D19-32	Open End Diesel Hammer	1820	600	No	57.6
S1 (Vert.)					No	
S3 (Vert.)					No	

Pile Driving Details

Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)
Crane*	Fixed*

Hiley Test Results

Pile No.	Ultimate Compression Resistance (kN)
S9 (Vert.)	3327
S1 (Vert.)	3455
S3 (Vert.)	4195

Pile Driving Analyzer Data

Pile No.	Event	Equivalent Pres. (Blows/ 25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
S9 (Vert.)	EOID	20	27	43	46.9	2800	199	3400
S1 (Vert.)	BOR	10/<1	27	43	46.9	2950	209	3700
S3 (Vert.)	BOR	10/<1	28	43	48.6	2920	207	3800

CAPWAP

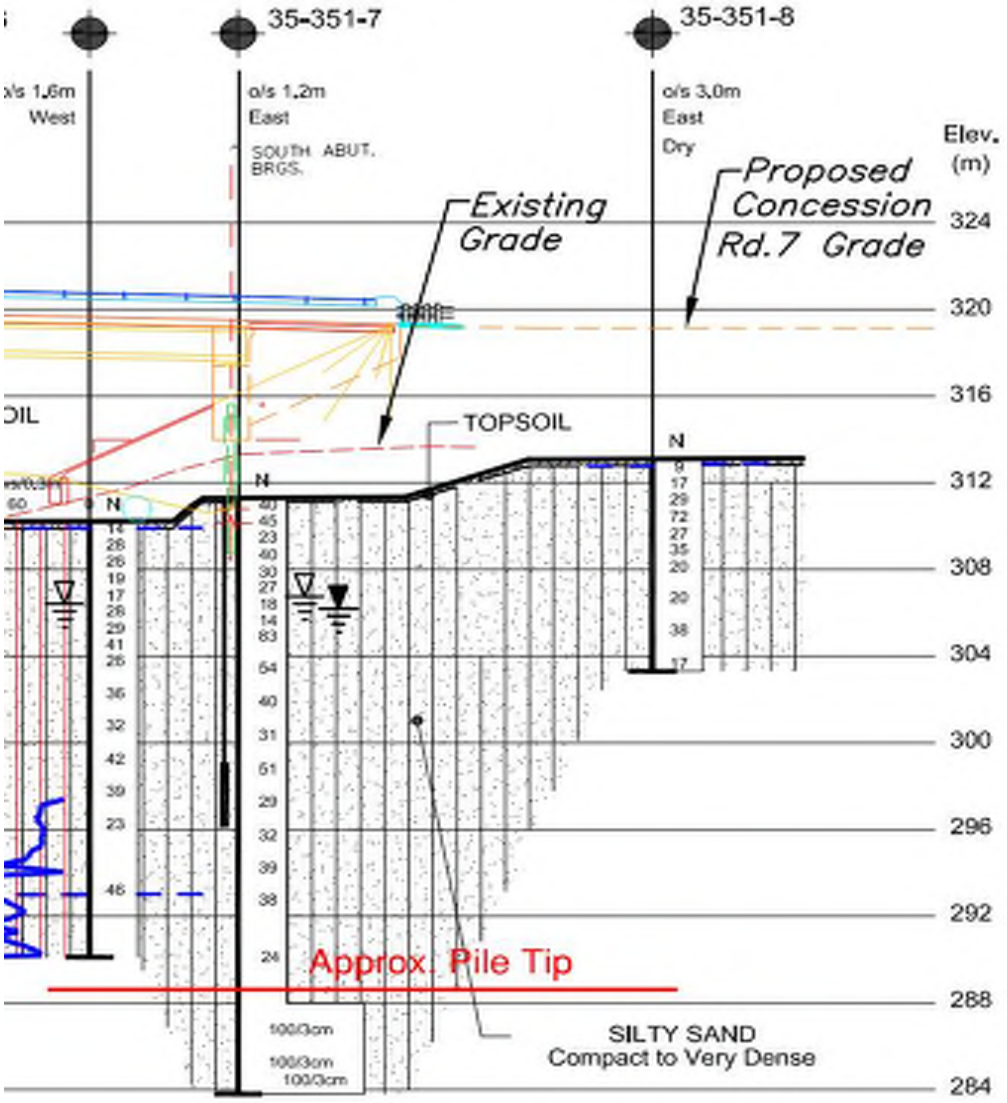
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
S9 (Vert.)	EOID	20/25	500	15	2900	85	3400	End Bearing
S1 (Vert.)	-	-	-	-	-	-	-	-
S3 (Vert.)	-	-	-	-	-	-	-	-

Pile Des. Capacity, FIDR (kN)

Factored ULS	SLS
1600	Not given**

*Note: Pile driving equipment and lead assumed based on hammer type used to perform Hiley/PDA test.
**Note: Not given, loads required to produced detrimental deformation are anticipated to be larger than factored ULS resistance.

Soil Stratigraphy at Pile Locations



Site No:	2	Project:	Gilles Creek Bridge Replacement, Site No. 39E-0006/B0

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

FIDR	Contract Drawings	Pile Load Test Report	PDA Report	Pile Logs
Gilles Creek Bridge Replacement, Site No. 39E-0006/B0, Highway 579 - Station 19+473, Town of Cochrane, Ontario, G.W.P. 5267-11-00, W.P. 5368-11-01, Latitude and Longitude: 49.11283, -81.27235 (Aug. 1, 2019)	2020-5116	N.A.	Foundation Specialist Services, Highway 579 Gilles Creek Bridge Replacement (Site #39E-0006/B0), North and South Abutments, WP 5368-11-01, WP 5267-11-00 - Northeastern Region, Ministry of Transportation Ontario, Contract No. 2020-5116	No Specfic Report, Data Provided in Individual Sheets

Pile I.D.	Soil Stratum	Pile Type
NA-1 (B1:10)	Cohesionless	End Bearing
NA-2 (Vert.)	Cohesionless	End Bearing
NA-3 (Vert.)	Cohesionless	End Bearing
NA-4 (Vert.)	Cohesionless	End Bearing
NA-5 (Vert.)	Cohesionless	End Bearing
SA-7 (B1:10)	Cohesionless	End Bearing
SA-8 (Vert.)	Cohesionless	End Bearing
SA-9 (Vert.)	Cohesionless	End Bearing
SA-10 (Vert.)	Cohesionless	End Bearing
SA-11 (Vert.)	Cohesionless	End Bearing
SA-12 (B1:10)	Cohesionless	End Bearing

Vert. Vertical Pile
B1:10 Battered at 10 Vertical to 1 Horizontal
EOID: End of Initial Drive

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
NA-5 (Vert.)	North Abutment	HP310 x 110	12.26	12.26	9.5	13.2	L125x125x13 280 long w/ spacer plates on web	-	233.0	223.5
NA-1 (B1:10)	North Abutment		13.79	10.71	10.0	14.9		-	235.0	225.0
NA-3 (Vert.)	North Abutment		12.25	11.21	10.5	13.2		-	235.0	224.5
NA-2 (Vert.)	North Abutment		12.26	10.78	10.0	13.2		-	234.9	224.9
NA-4 (Vert.)	North Abutment		12.26	10.78	10.0	13.2		-	234.9	224.9
SA-9 (Vert.)	South Abutment		12.26	10.34	9.5	13.2		-	234.8	225.3
SA-12 (B1:10)	South Abutment		13.8	10.33	9.5	14.9		-	234.8	225.3
SA-10 (Vert.)	South Abutment		12.26	10.98	10.0	13.2		-	234.6	224.6
SA-11 (Vert.)	South Abutment		12.26	10.85	10.0	13.2		-	234.8	224.8
SA-8 (Vert.)	South Abutment		12.26	10.91	10.0	13.2		-	234.7	224.7
SA-7 (B1:10)	South Abutment		13.79	10.83	10.0	14.9		-	234.8	224.8

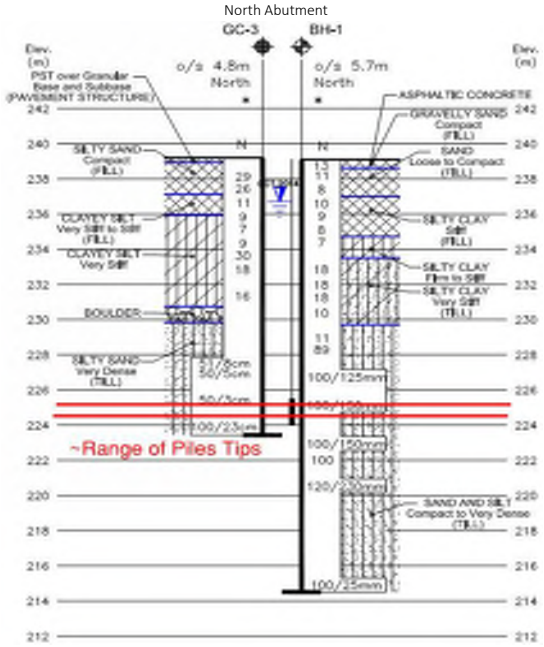
Hammer Specification							Pile Driving Details			Pile Design Capacity, FIDR (kN)	
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date	Factored ULS	SLS
NA-5 (Vert.)	Delmag D19-42	Diesel Hammer	1820	677	No	57.6	Linkbelt LS-108C Crane	Fixed	Nov. 19-20, 2020	1600	1200
NA-1 (B1:10)					No				Nov. 19, 2020		
NA-3 (Vert.)					No				Nov. 19, 2020		
NA-2 (Vert.)					No				Nov. 19, 2020		
NA-4 (Vert.)					No				Nov. 19-20, 2020		
SA-9 (Vert.)					No				Nov. 26, 2020		
SA-12 (B1:10)					No				Nov. 26, 2020		
SA-10 (Vert.)					No				Nov. 26, 2020		
SA-11 (Vert.)					No				Nov. 26, 2020		
SA-8 (Vert.)					No				Nov. 27, 2020		
SA-7 (B1:10)					No				Nov. 27, 2020		

Pile No.	Date	Hiley Test Results		Pile Driving Analyzer Data						
		Event	Ultimate Compression Resistance (kN)	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
NA-5 (Vert.)	Nov. 19, 2020	EOID	3100	EOID	5.8	37	37	64.2	237	2400
NA-1 (B1:10)	Nov. 19, 2020	EOID	3800	EOID	8.6	35	37	60.8	220	2800
NA-3 (Vert.)	Nov. 19, 2019	EOID	3150	EOID	6.3	36	38	62.5	226	2500
NA-2 (Vert.)	Nov. 19, 2020	EOID	4200	EOID	6.8	35	37	60.8	234	2700
NA-4 (Vert.)	Nov. 20, 2020	EOID	4100	EOID	4.2	35	38	60.8	224	2000
SA-9 (Vert.)	Nov. 26, 2020	EOID	3200	EOID	4.2	35	38	60.8	227	2000
SA-12 (B1:10)	Nov. 26, 2020	EOID	4000	EOID	4.2	34	37	59.0	220	2200
SA-10 (Vert.)	Nov. 26, 2020	EOID	2250	EOID	2.6	34	39	59.0	220	1550
SA-11 (Vert.)	Nov. 26, 2020	EOID	3100	EOID	3.5	35	38	60.8	232	1900
SA-8 (Vert.)	Nov. 27, 2020	EOID	2400	EOID	2.7	34	39	59.0	215	1800
SA-7 (B1:10)	Nov. 27, 2020	EOID	2800	EOID	3.6	34	38	59.0	216	1950

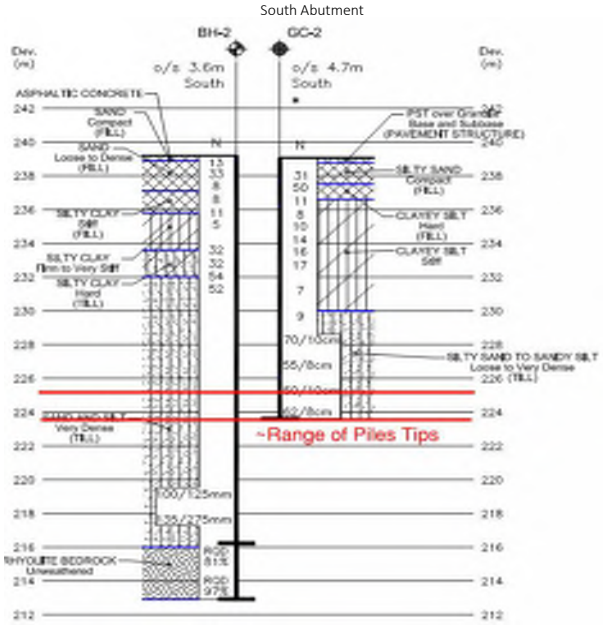
CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
NA-5 (Vert.)	-	-	-	-	-	-	-	-
NA-1 (B1:10)	-	-	-	-	-	-	-	-
NA-3 (Vert.)	-	-	-	-	-	-	-	-
NA-2 (Vert.)	-	-	-	-	-	-	-	-
NA-4 (Vert.)	EOID	6 (set/blow)	600	30	1400	70	2000	End Bearing
SA-9 (Vert.)	-	-	-	-	-	-	-	-
SA-12 (B1:10)	-	-	-	-	-	-	-	-
SA-10 (Vert.)	EOID	9.8 (set/blow)	350	23	1200	77	1550	End Bearing
SA-11 (Vert.)	-	-	-	-	-	-	-	-
SA-8 (Vert.)	-	-	-	-	-	-	-	-
SA-7 (B1:10)	-	-	-	-	-	-	-	-

Soil Stratigraphy

North Abutment



South Abutment



Site No:	3	Project:	Highway 9, Holland Drainage Canal Bridge Replacement	Pile Load Test	No
				PDA Test	Yes
				Hiley Test	Yes

Document Type	Document Title
FIR	Preliminary Foundation Investigation and Design Report, Highway 9, Holland Drainage Canal Bridge Replacement, Township of King, Site No. 37-030, G.W.P. 2188-08-00, Geocres No. 31D-553
Contract Dwgs	2016-2014
Pile Load Test Report	N.A.
Memo	Stantec: PDA Results on Test Piles, East Abutment, Holland Canal (Rev. 1.0), August 3, 2016
Memo	Stantec: PDA Results on Test Piles, East Abutment Stage 2, Holland Canal, Nov. 10, 2017
Memo	Stantec: PDA Results on Test Piles, Centre Pier Stage 2, Holland Canal (Revised), Oct. 25, 2017
Memo	Stantec: PDA Results on Test Piles, West Abutment Stage 2, Holland Canal, Dec. 4, 2017
PDA Report	EXP: Dynamic Analysis of Piles, Holland Marsh Drainage Canal, East Abutment, Hwy. 9 West of Hwy. 400, Project No. 2016-1014, July 29, 2016
PDA Report	EXP: Dynamic Analysis of Piles, Holland Marsh Drainage Canal, East Abutment (Stage II), November 1, 2017 Visit, Hwy. 9 West of Hwy. 400, Project No. 2016-1014, Nov. 3, 2017
PDA Report	EXP: Dynamic Analysis of Piles, Holland Marsh Drainage Canal, Centre Pier (Stage II), October 18, 2017 Visit, Hwy. 9 West of Hwy. 400, Project No. 2016-1014, Oct. 20, 2017
PDA Report	EXP: Dynamic Analysis of Piles, Holland Marsh Drainage Canal, West Abutment (Stage II), November 27, 2017 Visit, Hwy. 9 West of Hwy. 400, Project No. 2016-1014, Nov. 29, 2017

Pile I.D.	Soil Stratum	Pile Type
EA-K1	Cohesive	Friction
EA-K4	Cohesive	Friction
G-10 (B1:6)	Cohesive	Friction
K-10 (Vert)	Cohesive	Friction
K-12 (Vert)	Cohesive	Friction
D-13 (B1:8)	Cohesive	Friction
F-15 (B1:8)	Cohesive	Friction
A-11 (Vert.)	Cohesive	Friction
B-15 (B1:8)	Cohesive	Friction

KEY PLAN

1 km 0 1 2 km

Vert.	Vertical Pile
B1:6	Battered at 6 Vertical to 1 Horizontal
B1:8	Battered at 8 Vertical to 1 Horizontal
EOID:	End of Initial Drive
BOR:	Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
EA-K1 (vert)	East Abutment	356mm OD x 6.4wt	23.9*	-	23.5	12.9*	Yes	Not Written	218.5	195.0
EA-K4 (vert)	East Abutment	356mm OD x 6.4wt	24.3*	-	23.5	13.2*	Yes	Not Written	218.5	195.0
G-10 (B1:6)	East Abut. (Stg. 2)	HP310 x 79	25.66	-	22	19.9	Yes	13.77	218.2	196.2
K-10 (Vert)	East Abut. (Stg. 2)	HP310 x 79	25.66**	-	21.5	19.9	Yes	13.77**	218.1	196.6
K-12 (Vert)	East Abut. (Stg. 2)	HP310 x 79	25.66**	-	21.5	19.9	Yes	13.77**	217.5	196.0
D-13 (B1:8)	Center Pier (Stg. 2)	HP310 x 79	25.66	-	20.5	19.9	Yes	13.77	216.5	196.0
F-15 (B1:8)	Center Pier (Stg. 2)	HP310 x 79	24.09	-	20.75	18.7	Yes	13.81	216.55	195.8
A-11 (Vert.)	West Abut. (Stg. 2)	HP310 x 79	24.14	-	21	18.7	Yes	12.24	218.5	197.5
B-15 (B1:8)	West Abut. (Stg. 2)	HP310 x 79	24.45	-	21.1	18.9	Yes	12.22	218.1	197.0

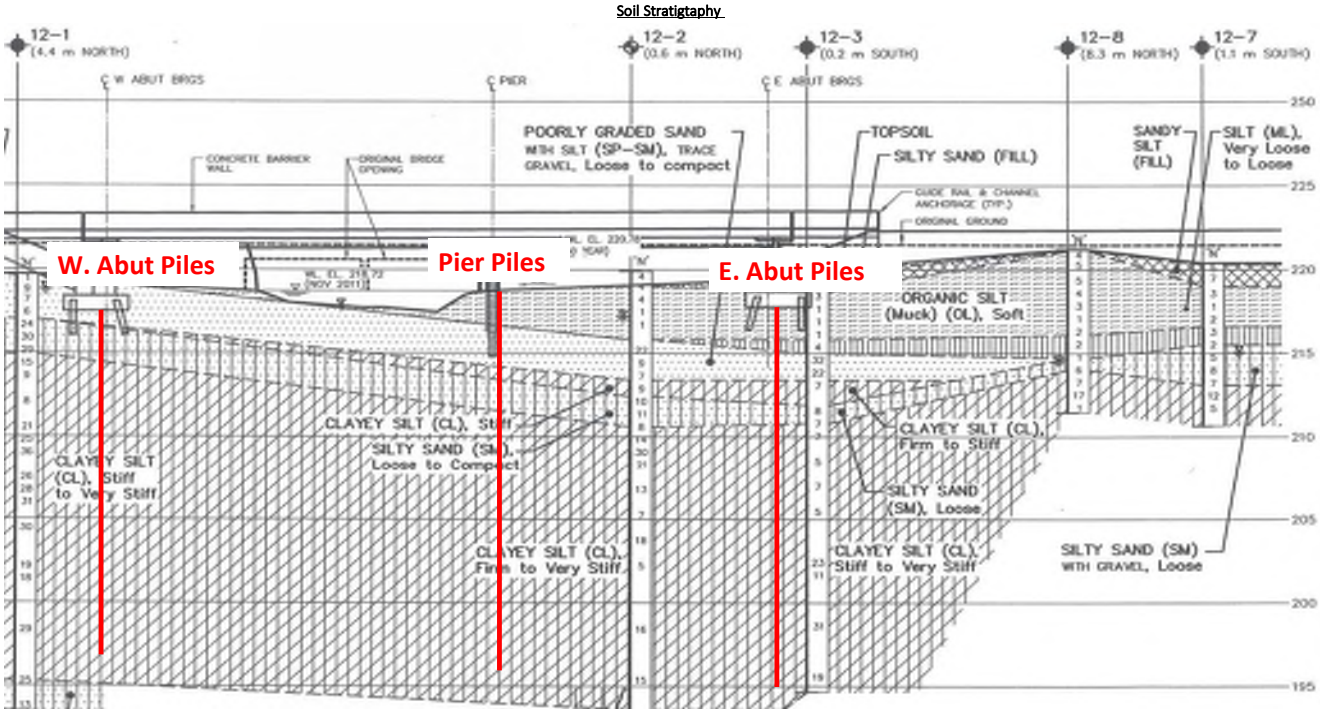
Hammer Specification							Pile Driving Details			Pile Des. Capacity, FIDR (kN)	
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date	Factored ULS	SLS
EA-K1	Delmag D19-32	Open End Diesel Hammer	1820	705	No	58	Crane***	Fixed***	Jul. 6, 2016	500****	500
EA-K4					No	58			Jul. 5, 2016		
G-10 (B1:6)					No	58			Oct. 30, 2017		
K-10 (Vert)					No	58			Oct. 31, 2017		
K-12 (Vert)					No	58			Nov. 3, 2017		
D-13 (B1:8)					No	58			Oct. 18, 2017		
F-15 (B1:8)					No	58			Oct. 18, 2017		
A-11 (Vert.)					No	58			Nov. 24, 2017		
B-15 (B1:8)					No	58			Nov. 24, 2017		

*Note:	Pile Length not written. 23.9/24.3 is distance below gages at approx. pile tip as shown in CAPWAP docs. Pile weight based on this assumed length.
**Note:	Pile length and splice not provided, assumed to be similar to other pile in pile group.
***Note:	Pile driving equipment and lead assumed based on hammer type used to perform Hiley/PDA test.
****Note:	Target ULS of 525 kN for East and West abutment and 475 kN for Centre Pier during Hiley/PDA testing per PDA memos.

Hiley Test Results				Pile Driving Analyzer Data								
Pile No.	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/ 25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
EA-K1	Jul. 20, 2016	BOR	919	Jul. 20, 2016	BOR	4.8	29	43	50.0	1820	259	950
EA-K4	Jul. 20, 2016	BOR	745	Jul. 20, 2016	BOR	22.7	15	47	25.9	1260	179	900
G-10 (B1:6)	Nov. 1, 2017	BOR	2081	Nov. 1, 2017	BOR	3.9	20	41	34.5	1990	199	1200
K-10 (Vert)	Nov. 6, 2017	BOR	2011	Nov. 6, 2017	BOR	4.6	19	44	32.8	2030	203	1100
K-12 (Vert)	Nov. 6, 2017	BOR	2183	Nov. 6, 2017	BOR	4.8	19	44	32.8	2040	204	1100
D-13 (B1:8)	Oct. 18, 2017	BOR	1487	Oct. 18, 2017	BOR	3.0	18	47	31.0	1860	186	700
F-15 (B1:8)	Oct. 18, 2017	BOR	1204	Oct. 18, 2017	BOR	2.0	21	45	36.2	1800	180	600
A-11 (Vert.)	Nov. 27, 2017	BOR	2076	Nov. 27, 2017	BOR	6.0	20	43	34.5	2010	201	1350
B-15 (B1:8)	Nov. 27, 2017	BOR	2084	Nov. 27, 2017	BOR	4.8	18	44	31.0	1960	196	1250

CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
EA-K1	BOR	10/52	700	74	250	26	950	Friction
EA-K4	BOR	10/11	675	75	225	25	900	Friction
G-10 (B1:6)	BOR	6.4 mm/blow	800	67	400	33	1200	Friction
K-10 (Vert)	-	-	-	-	-	-	-	-
K-12 (Vert)	-	-	-	-	-	-	-	-
D-13 (B1:8)	-	-	-	-	-	-	-	-
F-15 (B1:8)	BOR	13.3 mm/blow	450	75	150	25	600	Friction
A-11 (Vert.)	-	-	-	-	-	-	1350	-
B-15 (B1:8)	BOR	5.2 mm/blow	950	76	300	24	1250	Friction

Soil Stratigtaphy



Site No:	4	Project:	Highway 400/89 Underpass Replacement, G.W.P. 2438-13-00	Pile Load Test	Yes
				PDA Test	Yes
				Hiley Test	Yes

Document Type	Document Title
FIDR	Highway 400/89 Underpass Replacement, Structure Site No. 30-256, Reconstruction of Highway 400/89 Interchange, Town of Innisfil, Simcoe County, MTO G.W.P. 2438-13-00 (Nov. 20, 2018)
Tech. Memo.	Geotechnical Investigation Near Test Pile, Reconstruction of Highway 400 and Highway 89 Interchange, Cookstown, Ontario, MTO Contract No. 2018-2024, MTO Assignment No. 2018-C-0373 (Aug. 25, 2020)
Contract Dwgs	2018-2024
Pile Load Test Report	Report LT-1, Static Load Testing at Highway 400-89, Highway 400-89 Interchange Reconstruction, Site 30-256, MTO 2018-4019 (Oct. 15, 2019)
Pile Load Test Report	Report LT-2, Static Load Testing at Highway 400-89, Highway 400-89 Interchange Reconstruction, Site 30-256, MTO 2018-4019 (Oct. 31, 2019)
Pile Load Test Report	Report LT-3, Static Load Testing at Highway 400-89, Highway 400-89 Interchange Reconstruction, Site 30-256, MTO 2018-4019 (Nov. 15, 2019)
PDA Results/Hiley/ Pile Logs	Pile Installation Summary, Highway 400/89 Underpass Replacement Structure (Site No. 30-256), Reconstruction of Highway 400/89 Interchange, Town of Innisfil, Simcoe County, MTO G.W.P. 2438-13-00 (Feb. 24, 2021)

Separate Pile Load Test and PDA Summary on HP310x110 Pile (Northwest of Underpass)

Test Specimen: All tests completed on same 310x110 pile
Failure Criteria: Davisson Offset Load Limit Method
Testing Method: ASTM D1143M Procedure B - Maintained Test
Purpose: To investigate the axial resistances of a driven steel 310 x 110. For test 3 and 4, the pile was driven deeper to ~50.8 m to achieve greater capacity.

Pile Load Tests

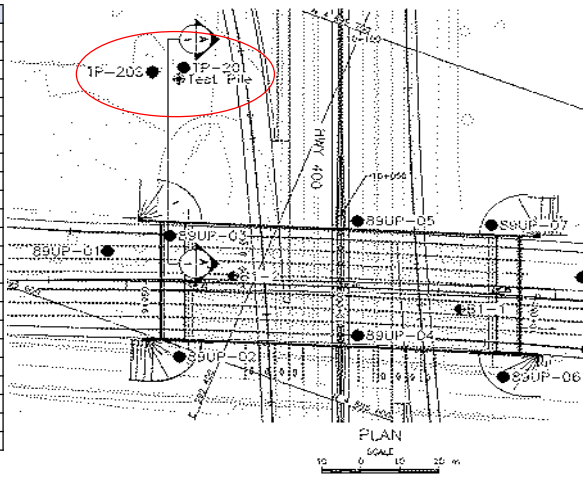
Test #	Date	Driven Depth (m)	Ult. Capacity (kN)	Reason for Test Termination
1	Oct. 7-8, 2019	36.34	780	Excessive movement, load reduced after max load achieved
2	Oct. 9-10, 2019	36.34	860	Excessive movement, load reduced after max load achieved
3	Oct. 28-19, 2019	50.8	1630	Excessive movement, load reduced and held 12 hrs
4	Nov. 12-13, 2019	50.8	1815	Load taken to 2400 kN for 20 min, then unloading phase

PDA Tests on Test Pile

Test #	Date	Event	Depth (m)	Ult. Capacity (kN)	Shaft Resistance kN)	Toe Resistance (kN)
1	Sep. 19, 2019	EOID	34-36	850	650	200
2	Sep. 19, 2019	BOR	36-36.34	1150	875	275
3	Oct. 11, 2019	EOD3	47.5 - 50.75	1500	975	525

Note: no hiley tests were performed for the test pile

Pile I.D.	Pile Location	Soil Stratum	Pile Type	Event
Test Pile (Test 1,2)	NW side of bridge	Cohesionless	End Bearing	-
Test Pile (Test 3,4)	NW side of bridge	Cohesionless	End Bearing	-
P3 (vert.)	East Abutment	Cohesionless	End Bearing	EOID
P3 (vert.)	East Abutment	Cohesionless	End Bearing	BOR
P15 (vert.)	East Abutment	Cohesionless	End Bearing	EOID
P15 (vert.)	East Abutment	Cohesionless	End Bearing	BOR
P25 (vert.)	East Abutment	Cohesionless	End Bearing	EOID
P25 (vert.)	East Abutment	Cohesionless	End Bearing	BOR
P2 (vert.)	West Abutment	Layered/Cohesionless	Friction/End Bearing	EOID
P2 (vert.)	West Abutment	Layered/Cohesionless	Friction/End Bearing	BOR
P16 (vert.)	West Abutment	Layered/Cohesionless	Friction/End Bearing	EOID
P16 (vert.)	West Abutment	Layered/Cohesionless	Friction/End Bearing	BOR
P24 (vert.)	West Abutment	Layered/Cohesionless	Friction/End Bearing	EOID
P24 (vert.)	West Abutment	Layered/Cohesionless	Friction/End Bearing	BOR
P2 (B1:6)	Pier	Layered/Cohesive	Friction/End Bearing	BOR
P3 (vert.)	Pier	Layered/Cohesive	Friction/End Bearing	BOR
P6 (vert.)	Pier	Layered/Cohesionless	Friction/End Bearing	BOR
P7 (vert.)	Pier	Layered/Cohesionless	Friction/End Bearing	BOR
P7 (vert.)	Pier	Layered/Cohesionless	Friction/End Bearing	BOR
P8 (vert.)	Pier	Layered/Cohesionless	Friction/End Bearing	EOID
P12 (vert.)	Pier	Cohesionless	End Bearing	EOID
P18 (vert.)	Pier	Cohesionless	End Bearing	EOID
P26 (vert.)	Pier	Cohesive	End Bearing	EOID



Vert.	Vertical Pile
EOID	End of Initial Strike
EOD3	End of third drive
BOR	Beginning of restike
B1:6	Battered at 6 Vertical to 1 Horizontal

Pile Information										Pile Design Capacity, FIDR (kN)	
Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)	Factored ULS	SLS
P3 (vert.)	East Abutment	HP310mm x 110 kg/m steel HP-Section	55.14	51.2	59.5	Pile Shoe	21.4/38.04	228.7	177.5	1600**	1250
P3 (vert.)	East Abutment		55.14	51.3	59.5	Pile Shoe	21.4/38.04	228.8	177.5		
P15 (vert.)	East Abutment		56.1	50.6	60.5	Pile Shoe	21.4/38.25	228.8	178.2		
P15 (vert.)	East Abutment		56.1	50.7	60.5	Pile Shoe	21.4/38.25	228.9	178.2		
P25 (vert.)	East Abutment		55.16	45.1	59.5	Pile Shoe	21.4/38.25	228.8	183.7		
P25 (vert.)	East Abutment		55.16	45.1	59.5	Pile Shoe	21.4/38.25	228.8	183.7		
P2 (vert.)	West Abutment		55	46.6	59.4	Pile Shoe	18.35/36.65	228.50	181.9		
P2 (vert.)	West Abutment		55	46.6	59.4	Pile Shoe	18.35/36.65	228.50	181.9		
P16 (vert.)	West Abutment		55.1	48.9	59.5	Pile Shoe	18.35/36.72	228.70	179.8		
P16 (vert.)	West Abutment		55.1	48.9	59.5	Pile Shoe	18.35/36.72	228.70	179.8		
P24 (vert.)	West Abutment		55.08	50.0	59.4	Pile Shoe	18.35/36.7	228.70	178.7		
P24 (vert.)	West Abutment		55.08	50.0	59.4	Pile Shoe	18.35/36.7	228.70	178.7		
P2 (B1:6)	Pier		55	50.5	59.4	Pile Shoe	18.3/36.7	228.20	177.7		
P3 (vert.)	Pier		51.96	48.5	56.1	Pile Shoe	18.34/36.66	227.80	179.3		
P6 (vert.)	Pier		51.92	44.7	56.0	Pile Shoe	18.34/36.68	227.60	182.9		
P7 (vert.)	Pier		52*	44.5	56.1	Pile Shoe	18.33/36.7	228.00	183.5		
P7 (vert.)	Pier		52*	44.5	56.1	Pile Shoe	18.33/36.7	228.00	183.5		
P8 (vert.)	Pier		52	44.6	56.1	Pile Shoe	18.35/33.66	228.10	183.5		
P12 (vert.)	Pier		52*	44.2	56.1	Pile Shoe	18.4/36.69	227.40	183.2		
P18 (vert.)	Pier		52*	44.2	56.1	Pile Shoe	18.4/36.69*	227.70	183.5		
P26 (vert.)	Pier		51.9	44.8	56.0	Pile Shoe	19.8/39.7	227.50	182.7		

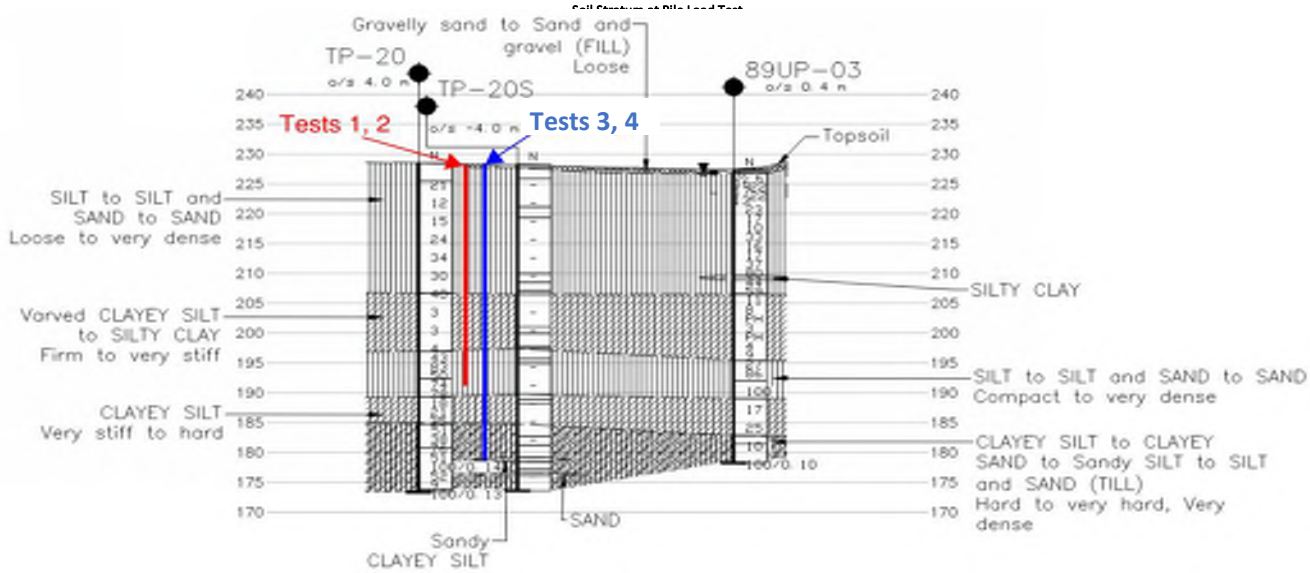
Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
P3 (vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	113	SC-90 HD Pile Driving VTL	Fixed	June 11, 2020
P3 (vert.)					No				June 11, 2020
P15 (vert.)					No				June 11, 2020
P15 (vert.)					No				June 11, 2020
P25 (vert.)					No				June 11, 2020
P25 (vert.)					No				June 11, 2020
P2 (vert.)					No				May 15, 2020
P2 (vert.)					No				May 15, 2020
P16 (vert.)					No				May 15, 2020
P16 (vert.)					No				May 15, 2020
P24 (vert.)					No				May 15, 2020
P24 (vert.)					No				May 15, 2020
P2 (B1:6)					No				Oct. 24, 2019
P3 (vert.)					No				Oct. 24, 2019
P6 (vert.)					No				Oct. 24, 2019
P7 (vert.)					No				Oct. 28, 2019
P7 (vert.)					No				Oct. 28, 2019
P8 (vert.)					No				Oct. 29, 2019
P12 (vert.)					No				Nov. 5, 2019
P18 (vert.)					No				Nov. 22, 2019
P26 (vert.)					No				Nov. 22, 2019

	Hiley Test Results			Pile Driving Analyzer Data								
Pile No.	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	ETR (%)	FMX (kN)	CSX (Mpa)	CSB (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
P3 (vert.)	June 11, 2020	EOID	3197	June 11, 2020	EOID	10.9	43.1	39	3191	223	166	2100
P3 (vert.)	June 16, 2020	BOR	4266	June 16, 2020	BOR	43.9	34.4	32	2974	215	116	2365
P15 (vert.)	June 11, 2020	EOID	3407	June 11, 2020	EOID	10.9	42.6	39	3120	220	138	2145
P15 (vert.)	June 16, 2020	BOR	3693	June 16, 2020	BOR	23.4	36.3	33	3021	217	130	2490
P25 (vert.)	June 11, 2020	EOID	3682	June 11, 2020	EOID	22.3	48.1	44	3308	237	231	2900
P25 (vert.)	June 16, 2020	BOR	3855	June 16, 2020	BOR	32.5	37.5	34	3146	223	175	2965
P2 (vert.)	May 15, 2020	EOID	3548	May 15, 2020	EOID	8.6	38.1	35	2979	209	160	2010
P2 (vert.)	May 22, 2020	BOR	5070	May 22, 2020	BOR	12.5	37.4	34	3165	224	147	2570
P16 (vert.)	May 22, 2020	EOID	3530	May 22, 2020	EOID	8.9	40.3	37	3010	211	149	1980
P16 (vert.)	May 27, 2020	BOR	3549	May 27, 2020	BOR	46	38.6	35	3141	229	130	2600
P24 (vert.)	May 15, 2020	EOID	3486	May 15, 2020	EOID	7.6	38.6	35	3108	218	153	2055
P24 (vert.)	May 22, 2020	BOR	3988	May 22, 2020	BOR	13.45	40.4	37	3195	226	154	2530
P2 (B1:6)	Oct. 29, 2019	BOR	3030	Oct. 29, 2019	BOR	20/25mm	38.9	35	3144	231	114	2100
P3 (vert.)	Oct. 29, 2019	BOR	3037	Oct. 29, 2019	BOR	25/25mm	43.5	40	3415	242	136	2500
P6 (vert.)	Oct. 29, 2019	BOR	3075	Oct. 29, 2019	BOR	33/25mm	41.6	38	3285	233	130	2840
P7 (vert.)	Oct. 29, 2019	BOR	2973	Oct. 29, 2019	BOR	22/25mm	42.2	38.4	3358	239	129	2150
P7 (vert.)	Nov. 1, 2019	BOR	4079	Nov. 1, 2019	BOR	19/25mm	50.1	46	3626	256	163	2690
P8 (vert.)	Oct. 29, 2019	EOID	3811	Oct. 29, 2019	EOID	19/25mm	41.6	37.8	3043	217	182	2005
P12 (vert.)	Nov. 5, 2019	EOID	3366	Nov. 5, 2019	EOID	10/25mm	48.8	44.7	3351	229	213	2360
P18 (vert.)	Nov. 22, 2019	EOID	3358	Nov. 22, 2019	EOID	11/25mm	44	40.3	3220	224	182	2240
P26 (vert.)	Nov. 22, 2019	EOID	3372	Nov. 22, 2019	EOID	26/25mm	43.5	39.9	3406	237	187	2450

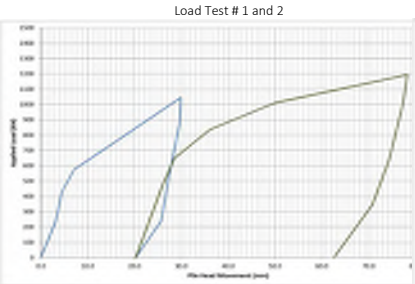
***Note:** Pile length and splice not written in provided pile logs. Length and splice assumed based on nearby piles in same pile group.

****Note:** Target ULS resistance of 1200 kN for pier and 1000 kN for abutments used during PDA/Hiley testing as per Pile Installation Summary.

CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
P3 (vert.)	EOID	-	711	34	1392	66	2103	End Bearing
P3 (vert.)	BOR	-	943.4	40	1420.4	60	2363.8	End Bearing
P15 (vert.)	EOID	-	841.5	39	1304	61	2145.5	End Bearing
P15 (vert.)	BOR	-	1042.3	42	1449.1	58	2491.4	End Bearing
P25 (vert.)	EOID	-	288.6	10	2607.1	90	2895.7	End Bearing
P25 (vert.)	BOR	-	670.2	23	2296.4	77	2966.6	End Bearing
P2 (vert.)	EOID	-	643.2	32	1367	68	2010.2	End Bearing
P2 (vert.)	BOR	-	1200.2	47	1373.7	53	2573.9	End Bearing
P16 (vert.)	EOID	-	727.6	37	1251.4	63	1979	End Bearing
P16 (vert.)	BOR	-	1277.2	49	1326.2	51	2603.4	End Bearing
P24 (vert.)	EOID	-	830.6	40	1224.3	60	2054.9	End Bearing
P24 (vert.)	BOR	-	1245.3	49	1286.8	51	2532.1	End Bearing
P2 (B1:6)	BOR	-	1052	50	1050	50	2102	Friction
P3 (vert.)	BOR	-	1304	52	1200	48	2504	Friction
P6 (vert.)	BOR	-	1476	52	1364	48	2840	Friction
P7 (vert.)	BOR	-	1076	50	1078	50	2154	End Bearing
P7 (vert.)	BOR	-	1241	46	1450	54	2691	End Bearing
P8 (vert.)	EOID	-	906	45	1100	55	2006	End Bearing
P12 (vert.)	EOID	-	793	34	1567	66	2360	End Bearing
P18 (vert.)	EOID	-	893	40	1347	60	2240	End Bearing
P26 (vert.)	EOID	-	897	37	1554	63	2451	End Bearing



Load Test # 1 and 2



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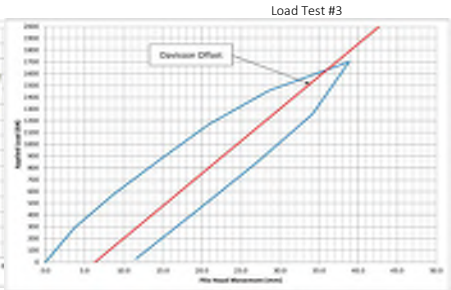

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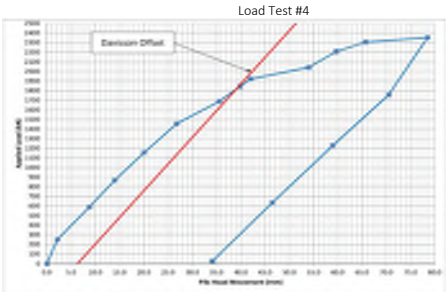
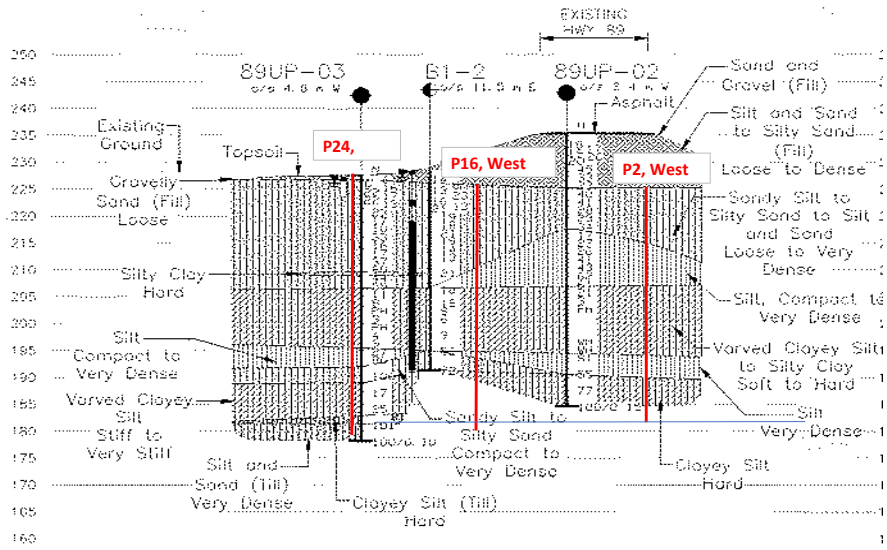
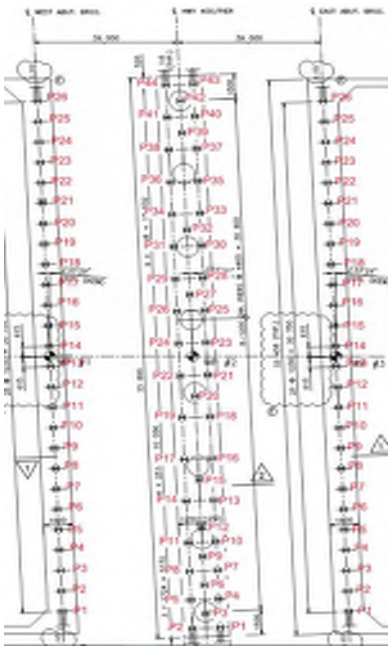
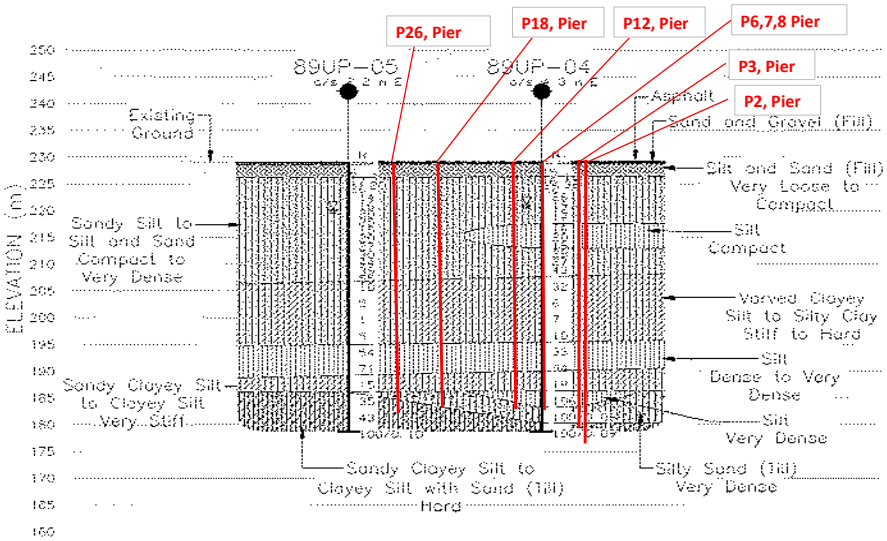


Soil Statrum for Piles Tested with PDA and Hiley at H400/89 Underpass Structure

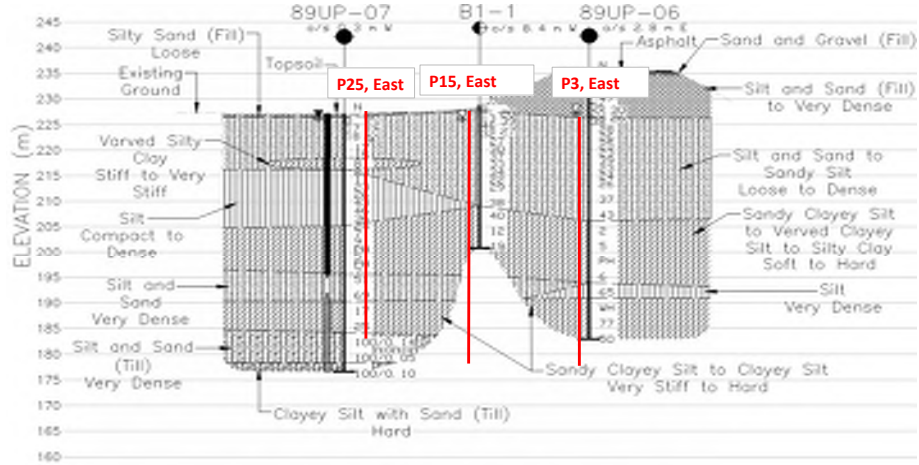


SCALE 1:500 G-B WEST ABUTMENT





SCALE 1:500 G-C CENTRE PIER



SCALE 1:500 D-D EAST ABUTMENT

Site No:	5	Project:	Essa Road Overpass, Highway 400 Widening, GWP 06-20016/G.W.P. 2337-16-00	Pile Load Test	Yes
				PDA Test	Yes
				Hiley Test	Yes

FIDR	Contract Drawings	Pile Load Test Report	Pile Logs
Essa Road (Simcoe Road 30) Overpass, Site No. 30-178, Highway 400 Widening from 1 km South of Highway 89 to Junction of Highway 11, Ministry of Transportation Ontario, G.W.P. 06-20016	N/A	Static Pile Load Test Report, Highway 400/Essa Road Overpass Replacement, City of Barrie, County of Simcoe, GWP 2337-16-00	Included in Pile Load Test Report

Purpose:
Assess the ultimate bearing resistance of HP310x110 piles used to support the Essa Road Overpass Structure.

Ultimate Capacity From Pile Load Test:

Test	Failure Criterion	Ult. Capacity (kN)	Reason for Test Termination
ASTM D1143M Quick Test	Davisson Offest	2600	Target cumulative pile displacement reached (30 mm)
	10% Pile Diameter	2300	
ASTM D1143M Maintained Test	Davisson Offest	3300	Flanges of test pile yielded at final load increment (200% design load)
	10% Pile Diameter	2750	

Event	Date
Pile Installed	Nov. 4, 2019
Hiley/PDA EOID	Nov. 4, 2019
Hiley/PDA BOR	Nov. 11, 2019
PLT: Quick Test	Dec. 10, 2019
PLT: Maintained Test	Jan. 13-14, 2019

Pile Type:	End Bearing
Soil Stratum:	Cohesionless

Location	Design Tip Elev. (m)	FactoredULS Res., FIDR* (kN)
North Abut.	229	850
	200	1200
Pier	229	800
	200	1200
South Abut.	229	800
	200	1200

*Note: Factored SLS resistance for 25 mm settlement will be greater than factored ULS resistance.

Vert. Vertical Pile
EOID = End of Initial Drive
BOR = Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
PLT-1 (vert.)	**West of Structure**	**HP310 x 110**	**33**	**31.6**	**31.6 to 31.8**	**35.6**	**Pile Shoe**	**16.8**	**246.20**	**214.6 to 214.4**
PLT-1 (vert.)	**West of Structure**		**33**	**31.6**	**31.8**	**35.6**	**Pile Shoe**	**16.8**	**246.20**	**214.4**

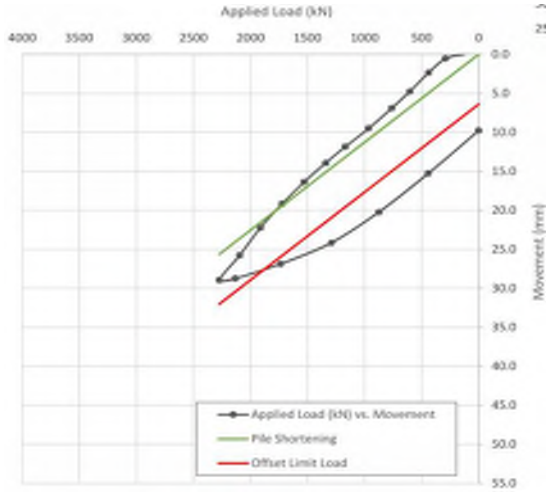
Hammer Specification							Pile Driving Details	
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Max. Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)
PLT-1 (vert.)	**LRH H40/7**	**Hydraulic Hammer**	**7000**	**600**	**No**	**55**	**LRH 100 Piling Rig**	**Fixed**
PLT-1 (vert.)								

Hiley Test Results			Pile Driving Analyzer Data							
Pile No.	Event	Ultimate Compression Resistance (kN)	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
PLT-1 (vert.)	**EOID**	**1675**	**EOID**	**13/118**	**34**	**-**	**62**	**2180**	**155**	**1500**
PLT-1 (vert.)	**BOR**	**1625**	**BOR**	**5/35**	**28**	**-**	**51**	**1920**	**136**	**1550**

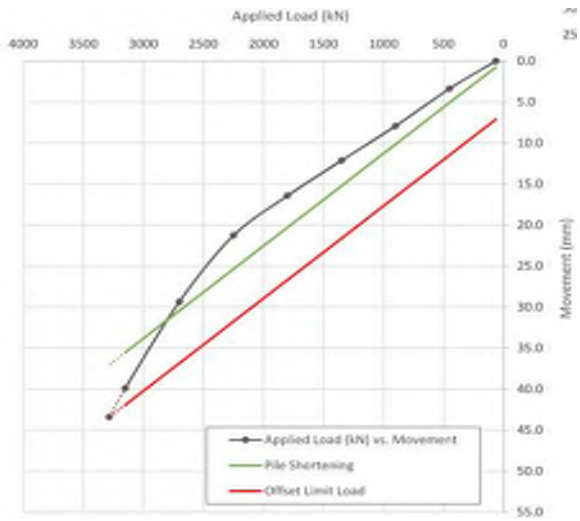
CAPWAP

Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
PLT-1 (vert.)	**-**	**-**	**-**	**-**		**-**	**-**	**-**
PLT-1 (vert.)	**BOR**	**5/35**	**600**	**39**	**950**	**61**	**1550**	**End Bearing**

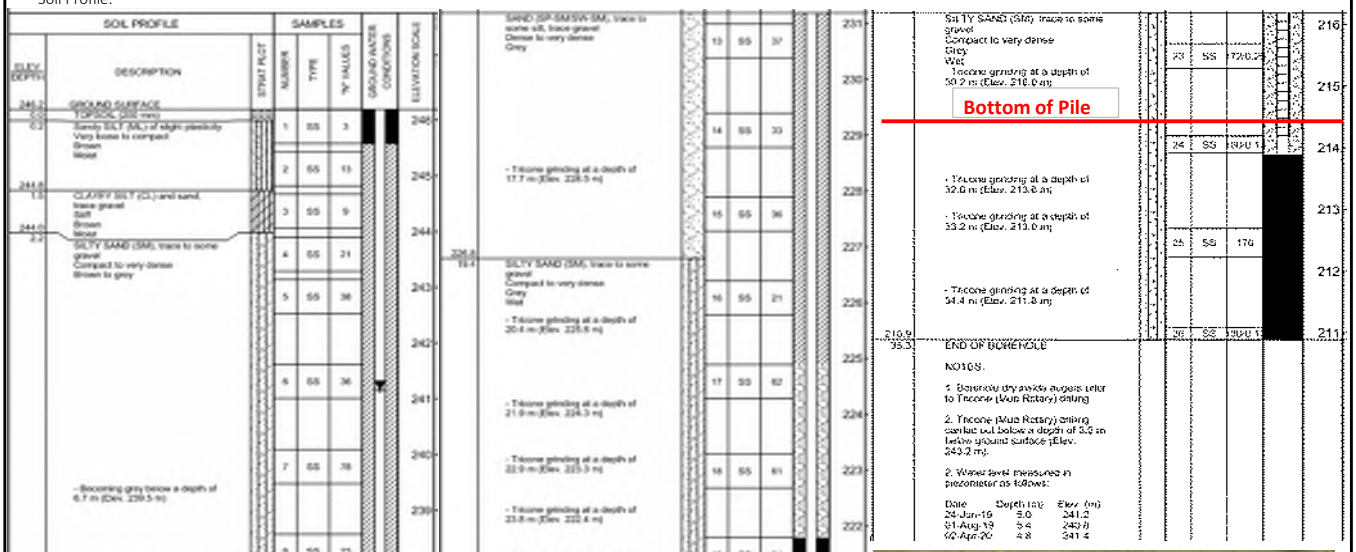
ASTM D1143M Quick Test

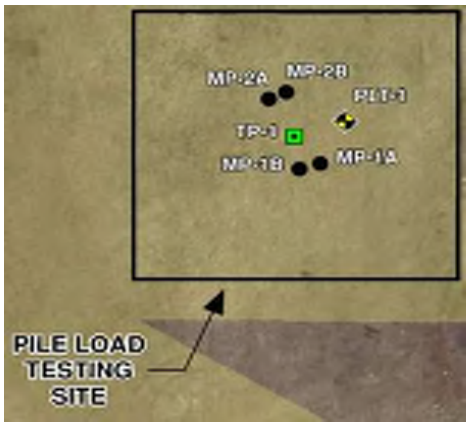


ASTM D1143M Maintained Test



Soil Profile:

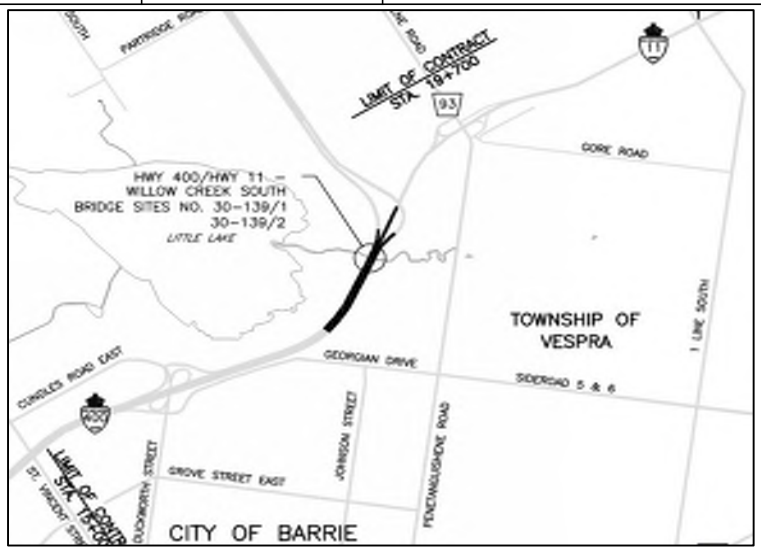




Site No:	6	Project:	Willow Creek Bridge Replacement, GWP NO. 2360-10-00	Pile Load Test	No
				PDA Test	Yes
				Hiley Test	Yes

FIDR	Contract Drawings	Pile Load Test Report	PDA Report	Pile Logs
Foundation Investigation and Design Report for Willow Creek Bridge Replacement, GWP NO. 2360-10-00; Site NO. 30-139/1&2, Highway 400, Barrie, Ontario (April 1, 2015, Revised April 21, 2015)	2016-2013	N.A.	PDA Field Report (EXP), Project No. BRM00607093-A0, Project: Willow Creek Bridge (Aug. 17, 2017)	Provided in unsorted documents, no official pile log report.

Soil Stratum	Cohesionless
Pile Type	End Bearing



Vert. Vertical Pile
BOR: Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Final Pile Tip Elevation (m)
95 (Vert.)	South Pier (S/W)	HP310 x 110	36.6	34.88	34.5	39.5	Yes	32.3	226.1	*Note

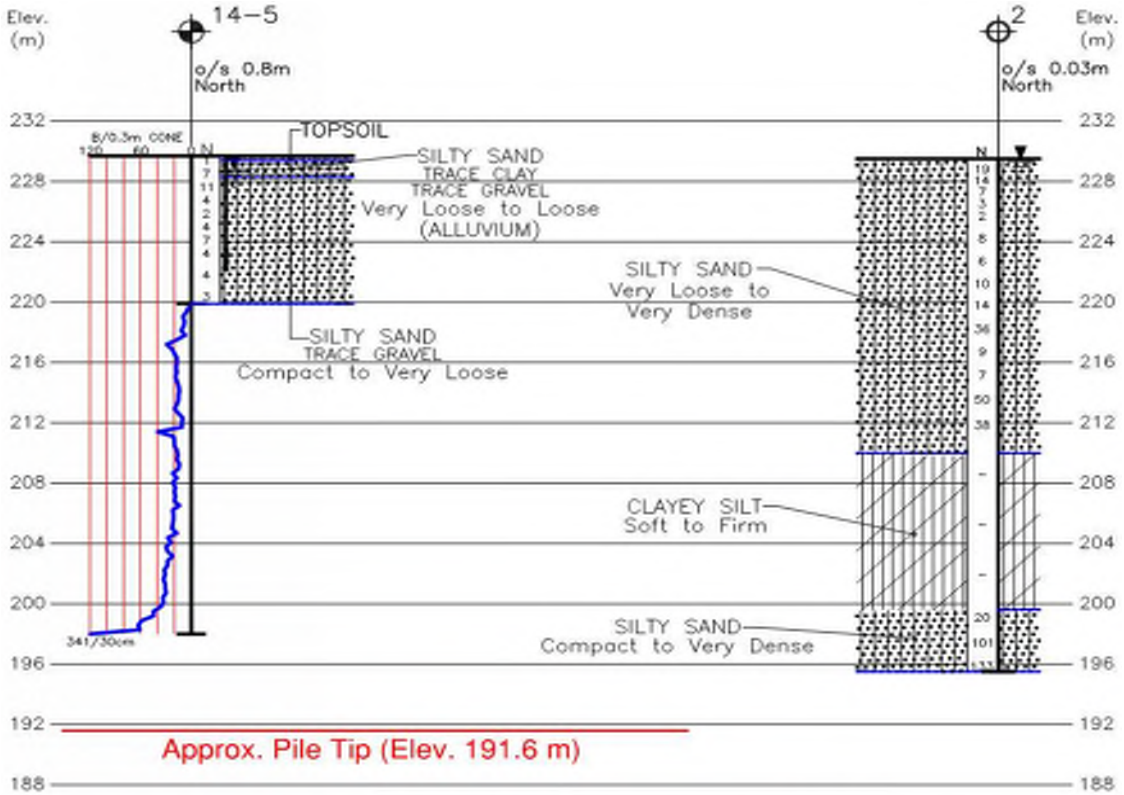
Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
95 (Vert.)	Pileco D30-32	Diesel Pile Hammer	3000	600	No	70	Crane*	Fixed*	Jul. 26, 2017

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)**	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
95 (Vert.)	Aug. 2, 2017	Retap	1680	Aug. 17, 2017	BOR	10.7	43	42	61.4	2870	203	3000
		Retap	2065									
		Retap	1643									
		Retap	1534									
		Retap	2645									
		Retap	2057									

CAPWAP									Pile Design Capacity, FIDR (kN)	
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type	Factored ULS	SLS
95 (Vert.)	No CAPWAP Data For This Project								1600***	1250

*Note: Pile driving equipment and lead assumed based on hammer type used to perform Hiley/PDA test.
**Note: Pile Tip at Elev. 196.7 m, 195.85 m, 194.85 m, 194.65, 192.35 m, and 192.15 m for Hiley result of 1680, 2065, 1643, 1534, 2645, 2057 kN respectively.
***Note: Target ULS resistance during PDA/Hiley testing was 1450 kN as per PDA Field Report

Soil Stratigraphy at Pile Location

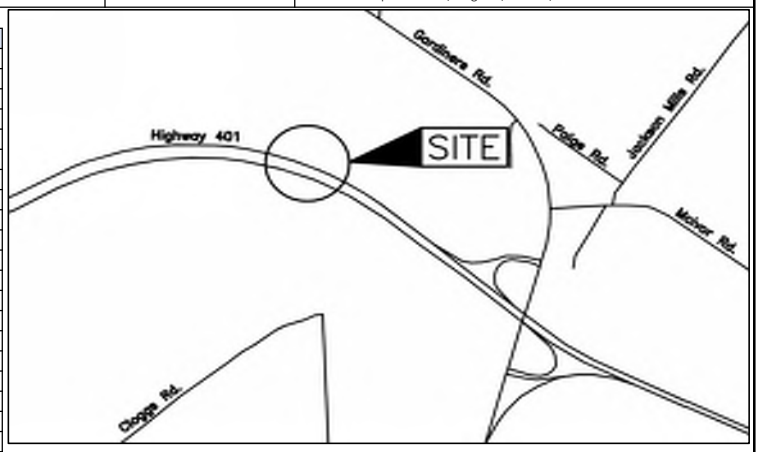


SECTION D-D ALONG ℄ SOUTH PIER

Site No: 7	Project: Collins Creek Bridge (Site No. 7-56/2), MTO GWP 4049-11-00	Pile Load Test	No
		PDA Test	Yes
		Hiley Test	Yes

FIDR	Contract Drawings	Pile Load Test	Pile Logs/PDA Reports
Foundation Investigation and Design Report, Collins Creek Bridge (Site No. 7-56/2) and Embankment Widening, Highway 401/Kingston Road 38 Interchange Improvements, Kingston, Ontario, MTO GWP 4049-11-00, Agreement No. 9016-E-0007, Assignment No. 1	2018-4011	N.A.	Pile Installation Summary, Collins Creek Bridge (Site No. 7-56/2) and Embankment Widening, Highway 401/Kingston Road 38 Interchange Improvements, Kingston, Ontario, MTO GWP 4049-11-00 Pile Installation Summary - Stage 2, Collins Creek Bridge (Site No. 7-56/2) and Embankment Widening, Highway 401/Kingston Road 38 Interchange Improvements, Kingston, Ontario, MTO GWP 4049-11-00

Pile I.D.	Soil Stratum	Pile Type	Event
WA2 (B10:1)	Cohesionless	Friction/End Bearing	EOID
WA2 (B10:1)	Cohesionless	Friction	BOR
WA4 (B10:1)	Cohesionless	Friction/End Bearing	EOID
WA4 (B10:1)	Cohesionless	Friction	BOR
EA1 (B10:1)	Cohesionless	End Bearing	EOID
EA2 (Vert.)	Cohesionless	Friction/End Bearing	BOR
EA2 (Vert.)	Cohesionless	Friction/End Bearing	BOR
EA3 (Vert.)	Cohesionless	Friction/End Bearing	BOR
EA3 (Vert.)	Cohesionless	End Bearing	EOID
EA4 (Vert.)	Cohesionless	End Bearing	EOID
EA4 (Vert.)	Cohesionless	End Bearing	BOR
EA5 (Vert.)	Cohesionless	End Bearing	BOR
EA6 (Vert.)	Cohesionless	End Bearing	BOR
WA10 (Vert.)	Cohesionless	Friction	BOR
WA10 (Vert.)	Cohesionless	Friction	EOID
WA13 (Vert.)	Cohesionless	Friction	EOID
WA14 (Vert.)	Cohesionless	Friction	BOR
EA8 (Vert.)	Cohesionless	End Bearing	EOID
EA8 (Vert.)	Cohesionless	End Bearing	BOR
EA9 (Vert.)	Cohesionless	End Bearing	EOID
EA9 (Vert.)	Cohesionless	End Bearing	BOR



EOID: End of Initial Drive
BOR: Beginning of Restrike
Vert. Vertical Pile
B10:1 Battered at 10 Vertical to 1 Horizontal

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approx. Ground Elevation (m)	Pile Tip Elevation (m)
WA2 (B10:1)	West abutment	HP12x74	16.8	-	15.3	18.1	Titus Hard Rock Injector Point	None	85.6	70.3
WA2 (B10:1)	West abutment	HP12x74	16.8	-	16.0	18.1		None	84.5	68.5
WA4 (B10:1)	West abutment	HP12x74	16.8	-	14.0	18.1		None	83.1	69.1
WA4 (B10:1)	West abutment	HP12x74	16.8	-	15.5	18.1		None	84.5	69
EA1 (B10:1)	East Abutment	HP12x74	18.6	-	16.7	20.1		None	84.8	68.1
EA2 (Vert.)	East Abutment	HP12x74	18.6	-	16.4	20.1		None	84.8	68.4
EA2 (Vert.)	East Abutment	HP12x74	18.6	-	18.4	20.1		None	85	66.6
EA3 (Vert.)	East Abutment	HP12x74	18.6	-	16.4	20.1		None	82.8	66.4
EA3 (Vert.)	East Abutment	HP12x74	18.6	-	18.6	20.1		None	84.4	65.8
EA4 (Vert.)	East Abutment	HP12x74	18.6	-	16.2	20.1		None	84.8	68.6
EA4 (Vert.)	East Abutment	HP12x74	18.6	-	16.2	20.1		None	84.8	68.4
EA5 (Vert.)	East Abutment	HP12x74	18.6	-	16.2	20.1		None	84.8	68.6
EA6 (Vert.)	East Abutment	HP12x74	18.6	-	16.4	20.1		None	85	68.6
WA10 (Vert.)	West Abutment	HP12x74	16.9	-	15.6	18.2	Titus standard "H" bearing pile point	None	84.6	69.0
WA10 (Vert.)	West Abutment	HP12x74	23.6	-	17	25.5		16.9	84.6	67.6
WA13 (Vert.)	West Abutment	HP12x74	22.4	-	17.8	24.2		16.9	84.8	67.0
WA14 (Vert.)	West Abutment	HP12x74	16.6	-	14.7	17.9		None	84.6	69.7
EA8 (Vert.)	East Abutment	HP12x74	18.6	-	17.3	20.1		13.8	85.1	67.8
EA8 (Vert.)	East Abutment	HP12x74	18.6	-	17.3	20.1		13.8	85	67.7
EA9 (Vert.)	East Abutment	HP12x74	18.6	-	17.6	20.1		None	85.1	67.5
EA9 (Vert.)	East Abutment	HP12x74	18.6	-	17.6	20.1		None	85	67.4

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installion Date
WA2 (B10:1)	Berminghammer B4505	Diesel Hammer	3000	601	No	103	BM700 Crane	Fixed	June 25, 2019
WA2 (B10:1)					No				June 25, 2019
WA4 (B10:1)					No				June 25, 2019
WA4 (B10:1)					No				June 25, 2019
EA1 (B10:1)					No				July 17, 2019
EA2 (Vert.)					No				July 17, 2019
EA2 (Vert.)					No				July 17, 2019
EA3 (Vert.)					No				July 17, 2019
EA3 (Vert.)					No				July 17, 2019
EA4 (Vert.)					No				July 17, 2019
EA4 (Vert.)					No				July 17, 2019
EA5 (Vert.)					No				July 17, 2019
EA6 (Vert.)					No				July 17, 2019
WA10 (Vert.)	Berminghammer B-3505	Diesel Hammer	1800	364	No	62			Oct. 24, 2019
WA10 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110			Oct. 24, 2019
WA13 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110			Oct. 25, 2019
WA14 (Vert.)	Berminghammer B-3505	Diesel Hammer	1800	364	No	62			Oct. 24, 2019
EA8 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110			Nov. 11, 2019
EA8 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110			Nov. 11, 2019
EA9 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110			Nov. 11, 2019
EA9 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110			Nov. 11, 2019

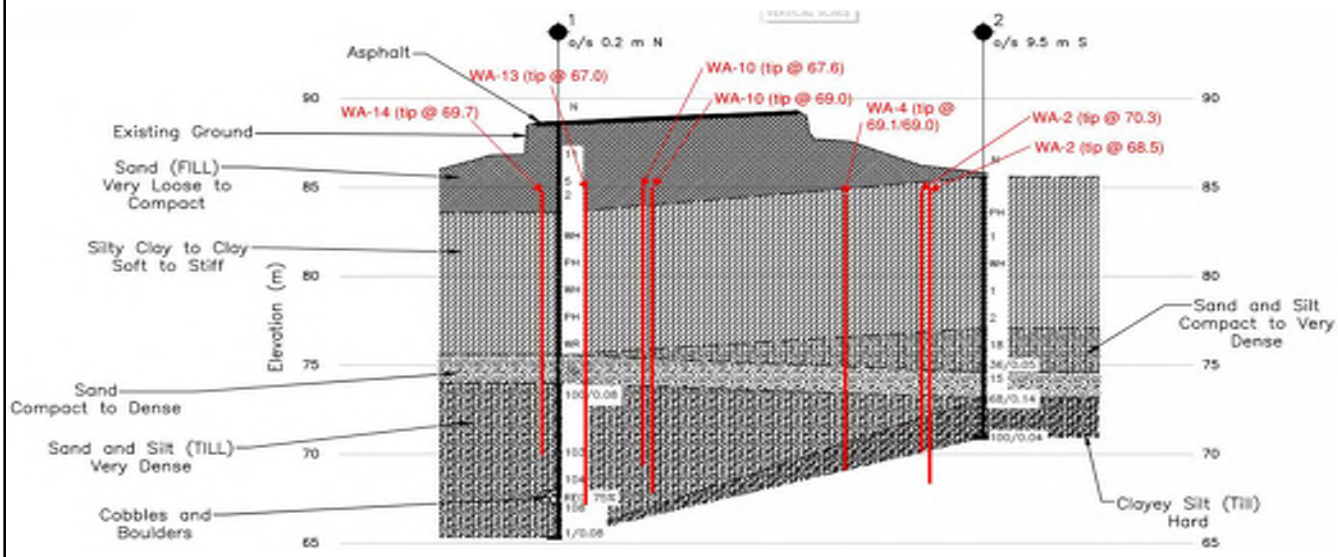
Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	ETR (%)	FMX (kN)	CSX (Mpa)	CSB (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
WA2 (B10:1)	June 25, 2019	EOID	2086	Jun. 25/19	EOID	3.1	28.6	27.8	2670	195	58	1165
WA2 (B10:1)	July 3, 2019	BOR	2712	Jul. 3/19	BOR	2.4	37.8	36.7	3332	250	69	1825
WA4 (B10:1)	June 25, 2019	EOID	2324	Jun. 25/19	EOID	1.9	40	38.8	2705	202	45	1200
WA4 (B10:1)	July 3, 2019	BOR	3254	Jul. 3/19	BOR	2.4	41.9	40.7	3247	239	63	1665
EA1 (B10:1)	July 17, 2019	EOID	2592	Jul. 17/19	EOID	1.7	34.8	33.8	3021	222	46	1310
EA2 (Vert.)	July 22, 2019	BOR	2592	Jul. 22/19	BOR	1.3	36.6	35.5	3210	225	69	1330
EA2 (Vert.)	July 25, 2019	BOR	2744	Jul. 25/19	BOR	2.2	40	38.8	3135	228	77	1785
EA3 (Vert.)	July 25, 2019	BOR	2828	Jul. 25/19	BOR	1.6	37.4	36.3	3146	228	60	1505
EA3 (Vert.)	July 25, 2019	EOID	2665	Jul. 25/19	EOID	0.8	36.3	35.2	2723	197	39	905
EA4 (Vert.)	July 17, 2019	EOID	2916	Jul. 17/19	EOID	2.6	38.3	37.2	3100	224	102	1755
EA4 (Vert.)	July 22, 2019	BOR	3332	Jul. 22/19	BOR	3.2	40.7	39.5	3120	226	101	2000
EA5 (Vert.)	July 25, 2019	BOR	2916	Jul. 25/19	BOR	2.3	38.1	37.0	3132	228	99	1540
EA6 (Vert.)	July 25, 2019	BOR	2744	Jul. 25/19	BOR	2.7	39.3	38.0	3002	218	77	1905
WA10 (Vert.)	Oct. 28, 2019	BOR	1687	Oct. 28/19	BOR	3.1	18	29	2317	169	70	1080
WA10 (Vert.)	Nov. 4, 2019	EOID	3299	Nov. 4/19	EOID	2.5	39.5	36	3170	225	84	1245
WA13 (Vert.)	Oct. 28, 2019	EOID	3067	Oct. 28/19	EOID	2.1	34.7	32	3017	216	61	1095
WA14 (Vert.)	Nov. 4, 2019	BOR	1954	Nov. 4/19	BOR	2.3	21.5	35	2579	184	36	1050
EA8 (Vert.)	Nov. 11, 2019	EOID	3866	Nov. 11/19	EOID	2.8	41	37	3416	231	151	1730
EA8 (Vert.)	Nov. 13, 2019	BOR	4789	Nov. 13/19	BOR	3	40.8	37	3456	237	127	1937
EA9 (Vert.)	Nov. 11, 2019	EOID	2982	Nov. 11/19	EOID	2.4	37.5	34	3310	225	132	1650
EA9 (Vert.)	Nov. 13, 2019	BOR	3934	Nov. 13/19	BOR	3.2	39.1	36	3465	235	122	1995

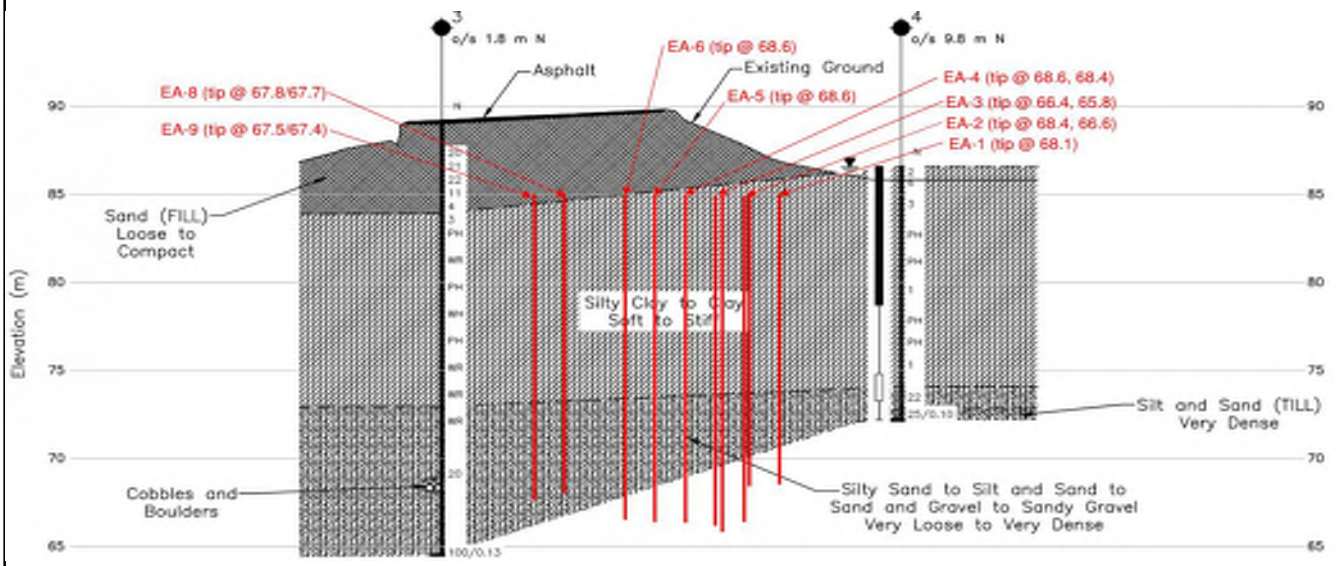
CAPWAP									Pile Design Capacity, FIDR (kN)	
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotech. Resistance (kN)	Pile Type	Factored ULS	SLS
WA2 (B10:1)	EOID	3.1	666	57	500	43	1166	Friction	1400*	The factored SLS for 25 mm of settlement will be equal or greater than ULS resistance
WA2 (B10:1)	BOR	2.4	1284	70	540	30	1824	Friction		
WA4 (B10:1)	EOID	1.9	658	55	543	45	1201	Friction		
WA4 (B10:1)	BOR	2.4	1144	69	520	31	1664	Friction		
EA1 (B10:1)	EOID	1.7	658	50	650	50	1308	Friction		
EA2 (Vert.)	BOR	1.3	807	61	524	39	1331	Friction		
EA2 (Vert.)	BOR	2.2	987	55	800	45	1787	Friction		
EA3 (Vert.)	BOR	1.6	902	60	603	40	1505	Friction		
EA3 (Vert.)	EOID	0.8	401	44	506	56	907	End Bearing		
EA4 (Vert.)	EOID	2.6	649	37	1104	63	1753	End Bearing		
EA4 (Vert.)	BOR	3.2	746	37	1254	63	2000	End Bearing		
EA5 (Vert.)	BOR	2.3	588	38	950	62	1538	End Bearing		
EA6 (Vert.)	BOR	2.7	863	45	1042	55	1905	End Bearing		
WA10 (Vert.)	BOR	3.1	720	67	360	33	1080	Friction		
WA10 (Vert.)	EOID	2.5	794	64	450	36	1244	Friction		
WA13 (Vert.)	EOID	2.1	795	73	300	27	1095	Friction		
WA14 (Vert.)	EOID	2.3	749	71	300	29	1049	Friction		
EA8 (Vert.)	EOID	2.8	664	38	1066	62	1730	End Bearing		
EA8 (Vert.)	BOR	3	812	42	1125	58	1937	End Bearing		
EA9 (Vert.)	EOID	2.4	625	38	1025	62	1650	End Bearing		
EA9 (Vert.)	BOR	3.2	876	44	1117	56	1993	End Bearing		

*** Note** Target ULS resistance for Hiley/PDA was 1300 kN as per Pile Installation Summary.

Soil Stratigraphy at Piles

Note: Pile locations shown are approximate.





Site No:	8	Project:	Fletcher's Creek Bridges, Highway 401 Widening, GWP 2150-01-00	Pile Load Test	Yes
				PDA Test	Yes
				Hiley Test	Yes

FIDR	Contract Drawings	Pile Load Test Report	Pile Logs
Fletcher's Creek Bridges, Highway 401 Widening from Highway 403/410 Interchange to the Credit River, City of Mississauga, Region of Peel, GWP 2150-01-00	Contract No. 2015-2018	FINAL STATIC PILE LOAD TEST REPORT, Highway 401/ Fletcher's Creek Bridges, Highway 401 Widening from Highway, 403/410 Interchange to the Credit River, City of Mississauga, Region of Peel, GWP 2150-01-00, Contract No. 2015-2018	Included in Pile Load Test Report

Ultimate Capacity From Pile Load Test:	> 2600 kN

Test Method: ASTM D1143-07 Procedure A - Quick Test

Test Termination:
Finally increment of 2600 kN pre-determined however it was observed pile did not fail at this load.

Purpose of PLT:
To confirm strength gain over time since retapping of bridge piles varied between higher and lower ultimate resistance from EOID Hiley tests.

Event	Date
Pile Installed	May 16-17, 2017
Hiley	Dec. 14, 2016
PDA	Dec. 14, 2016
Pile Load Test	May 16-17, 2017
NO RESTRIKE ON PDA/HILEY	

Vert. Vertical Pile
EOID: End of Intial Drive

Pile Type: End Bearing
Soil Stratum Cohesionless

Pile Information

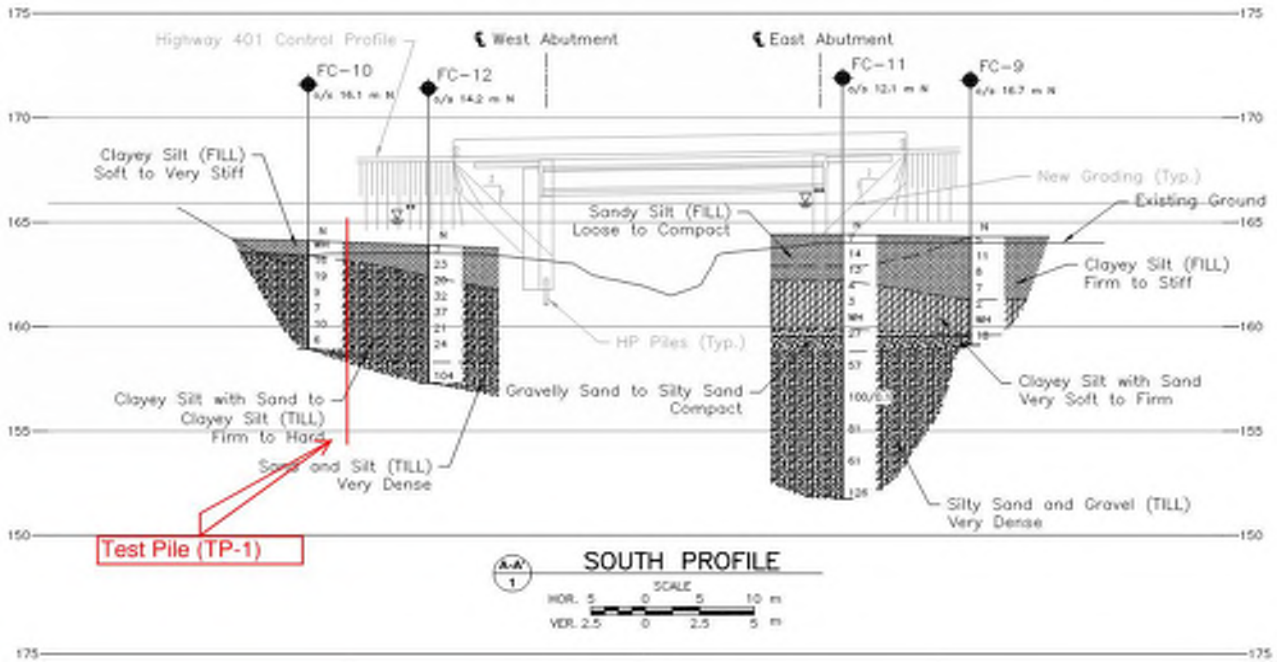
Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embed. Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
TP1 (Vert.)	**South Structure**	**HP310 x 110**	**16.77**		**9.6**	**18.1**	**Yes (type not specified)**	**None**	**164.0**	**154.4**

Hammer Specification							Pile Driving Details	
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)
TP1 (Vert.)	**Delmag D19-32**	**Diesel Hammer**	**1820**	**605**	**No**	**66**	**Crane***	**Fixed***

Hiley Test Results		Pile Driving Analyzer Data							
Pile No.	Ultimate Compression Resistance (kN)	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
TP1 (Vert.)	**2760**	**EOID**	**4.3**	**30**	**38**	**45.5**	**3040**	**216**	**2200**

CAPWAP								Pile Design Capacity, FIDR (kN)	
Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type	Factored ULS	SLS
EOID	**1/5.8**	**375**	**17**	**1825**	**83**	**2200**	**End Bearing**	**1000 (North Bridge) 900 (South Bridge)**	**800 (North Bridge) 700 (South Bridge)**

***Note:** **Pile driving equipment and lead assumed based on hammer type used to perform Hiley/PDA test.**


Highway 401 Control Profile
West Abutment
East Abutment
FC-10
FC-12
FC-11
FC-9
Clayey Silt (FILL)
Soft to Very Stiff
New Grading (Typ.)
Existing Ground
Sandy Silt (FILL)
Loose to Compact
Clayey Silt (FILL)
Firm to Stiff
HP Piles (Typ.)
Clayey Silt with Sand to
Clayey Silt (TILL)
Firm to Hard
Gravelly Sand to Silty Sand
Compact
Clayey Silt with Sand
Very Soft to Firm
Sand and Silt (TILL)
Very Dense
Silty Sand and Gravel (TILL)
Very Dense
Test Pile (TP-1)
SOUTH PROFILE
SCALE
HOR. 5 0 5 10 m
VER. 2.5 0 2.5 5 m

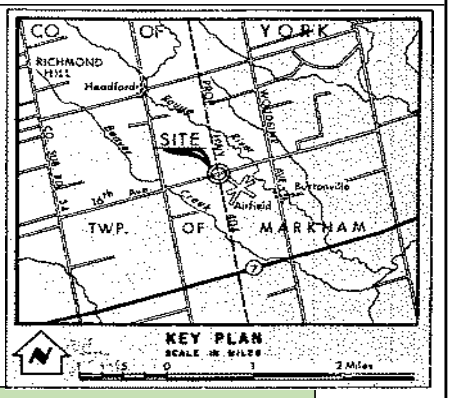
Combined Loading, Creep and Unloading Phases - Load vs. Displacement
Displacement (mm)
Load (kN)
Secondary Measurements
Dial Gauges

Site No:	9	Project:	Twin Overpass Structures at the Crossing of Hwy. #404 and 16th Avenue (Buttonville)	Pile Load Test	Yes
				PDA Test	Yes
				Hiley Test	Yes

Doument #	Document Type	Document Title
1	FIDR	Proposed Twin Overpass Structures, Hwy. 404 and 16th Avenue, W.P. 160-74-25, Site 37-666, Dist. 6 Toronto (Apr. 5 1977)
2	FIDR	Additional Borings at the Site of the Proposed Twin Overpass Structures at the Crossing of Hwy. #404 and 16th Avenue, Twp. Of Markham, County of York, District No. 6 (Toronto), W.O. 70-11103, W.P. 393-54 (Nov 17, 1971)
3	PDA Report	Pile Driving Analysis, M.T.C. Pile Load Test Program, Sixteenth Avenue & Proposed Highway No. 404, Buttonville, Ontario (Feb. 28, 1978)
4	PDA Memo	Pile Driving Analyzer Results, Highway 404 and 16th Avenue, Buttonville Site, W.P. 160-74-25 (March 3, 1980)
5	PLT Report	Pile Load Capacity Evaluation, Hwy 404 Structures (July 1978)
6	Contract Dwgs.	Not provided
7	Pile Logs	See Document #5

Purpose of PLT: To evaluate the comparative performance of various pile types to permit the selection of the most cost effective pile type/design load combination.

Test Method: ASTM D1143-74 Maintained Test



Pile I.D.	Soil Stratum	Pile Type	Reason for Test Termination
Test Pile #1	Cohesionless	End	Pile Reached Target Load
Test Pile #2	Cohesionless	End	Pile Reached Target Load
Test Pile #3	Cohesionless	End	Pile Reached Target Load
Test Pile #4	Layered	Friction	Pile Cap Shattered
Test Pile #5	Layered	Friction	Plunging Failure

EOID = End of Initial Drive
EOR = End of Restrike
All piles vertical.

Max. Allowable Load for HP12x74 pile per FIDR (kN)
845

Pile Information

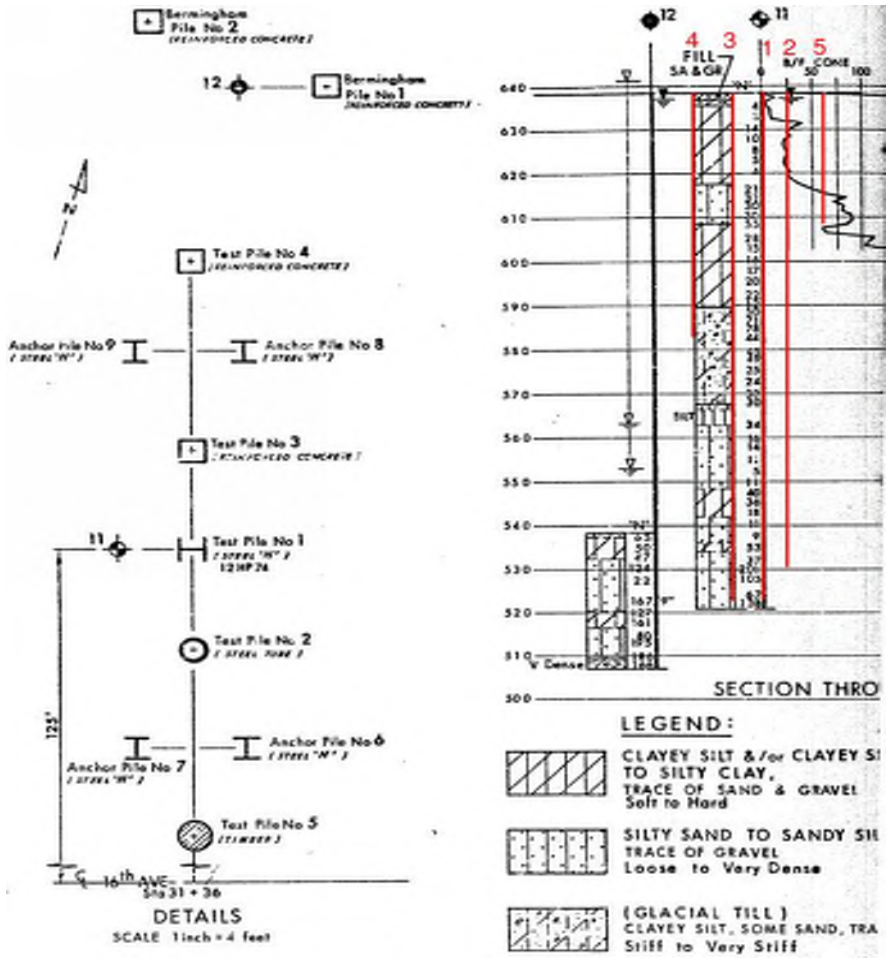
Pile I.D.	Pile Specification	Total Pile Length while driving (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/Bearing Point	Splice Location Below Top of Pile (m)	Approximate Ground Elevation at Pile (m)	Actual Pile Tip Elevation (m)
Test Pile #1	HP12x74	35.2	34.9	38.0	-	18.4	194.3	159.5
Test Pile #2	Closed End 311 ID/6.4WT	33.0	32.7	16.1	-	15.2 / 30.2	194.4	161.7
Test Pile #3	12"X12" precast rein conc	35.2	34.8	78.5	5/8" end plate	12.2/ 24.4/ 32.0	194.3	159.5
Test Pile #4	12"X12" precast rein conc	16.9	16.6	37.7	5/8" end plate	11.3	194.6	178.0
Test Pile #5	No14 Timber (16"butt,12" tip)	9.0	8.7	1.4 - 2.8*	-	-	194.3	185.6

Hammer Specification							Pile Driving Details		
Pile I.D.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/Piston (kg)	Weight of Anvil (kg)	Cushion	Rated Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Date Driven
Test Pile #1	Berminghammer B400	Open End Diesel Hammer	2268	636	No	62.4	Crane**	Fixed**	Oct. 28, 1977
Test Pile #2					No				Oct. 31, 1977
Test Pile #3					5x3/4" plywood				Nov. 1, 1977
Test Pile #4					5x3/4" plywood				Oct. 31, 1977
Test Pile #5	B-225		1364	500	No	39.3			Nov. 1, 1977

Hiley Test Results					PDA Results	Pile Load Test Results			
Pile I.D.	EOID Date	Restrike Date	Event	Ultimate Compression Resistance (kN)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Date of PLT	Ultimate Load (kN) Failure Criterion: Davisson	Ultimate Load (kN) Failure Criterion: M.T.C	Ultimate Load (kN) Failure Criterion: M.T.C
Test Pile #1	Oct. 28, 1977	Nov. 4, 1977	EOR	2295	3576	Nov. 14-15,1977	3559	3648	-
Test Pile #2	Oct. 31, 1977	Nov. 1, 1977	EOR	1868	2046	Nov. 21, 1977	2002	2402	2046
Test Pile #3	Nov. 1, 1977	Nov. 2, 1977	EOR	2491	2153	Nov. 17-18,1977	1779	1673	2358
Test Pile #4	Oct. 31, 1977	Nov. 1, 1977	EOR	3407	2091	Nov. 23, 1977	2002	2340	2473
Test Pile #5	Nov. 1, 1977	Nov. 2, 1977	EOID	2420	925	Nov. 24, 1977	890	783	979

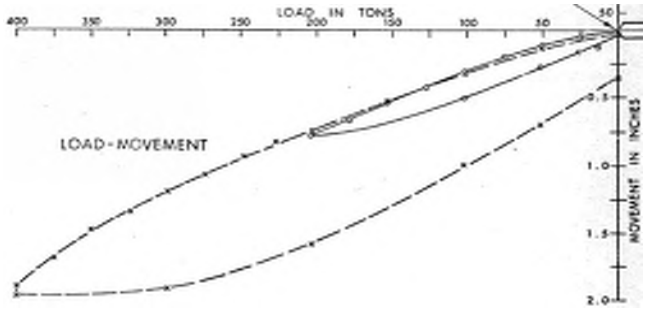
*Note: Total weight will driving is 1.4 to 2.8 kN assuming timber denstiy ranged from 390 to 810 kg/m³
**Note: This is not stated anywhere in the provided documents, may be assumed based on hammer system, however I don't know how to determine these details

Soil Stratigrapgy at Testing Site

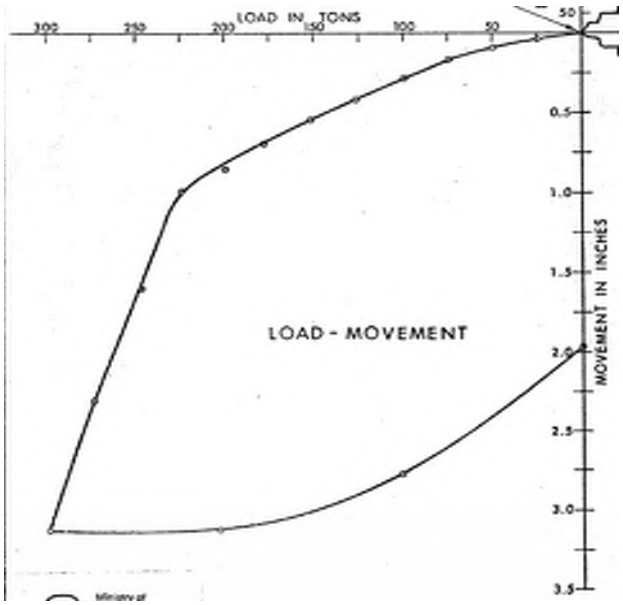


Load Displacement Curves from Pile Load Tests

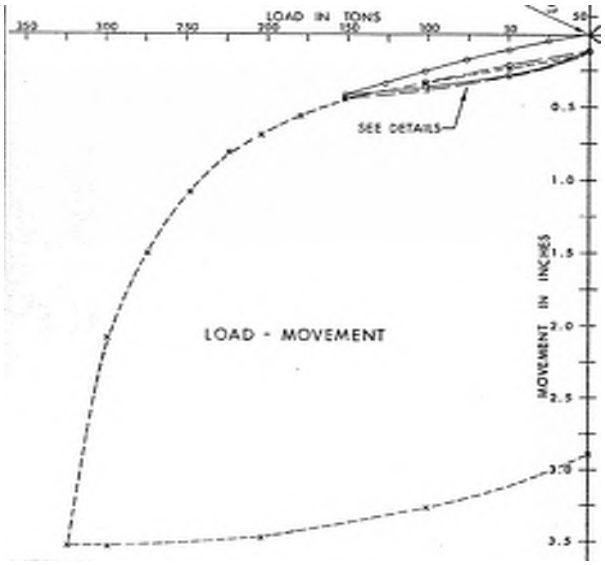
Test Pile #1



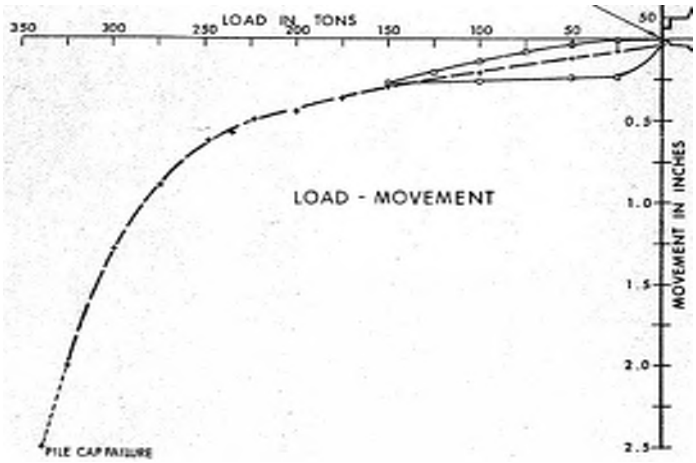
Test Pile #2



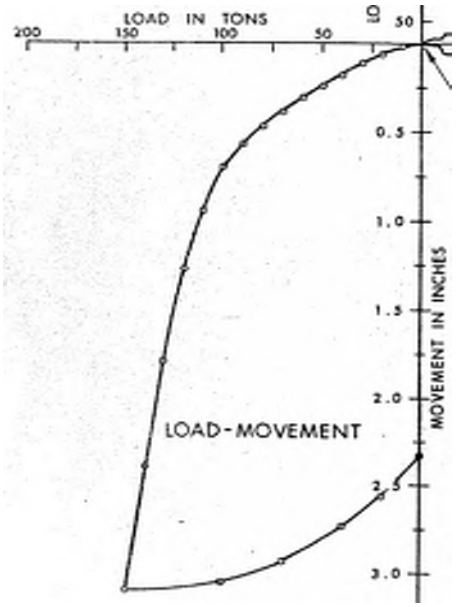
Test Pile #3



Test Pile #4



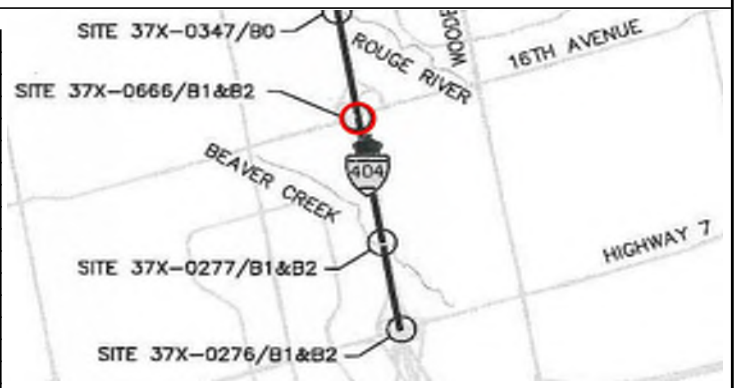
Test Pile #5



Site No:	10	Project:	Hwy 404 HOV Lane Expansion & Rehab (16th Avenue), G.W.P. 2930-17-00	Pile Load Test	No
				PDA Test	Yes
				Hiley Test	Yes

Document Type	Document Title
FIDR	Highway 404 16th Avenue Overpass, Replacement and Widening, Highway 404 HOV Lane Expansion and Rehabilitation, Contract 2, Markham Ontario, Site 37-666, G.W.P. 2930-17-00, Geocres. 30M14-487
Contract Dwgs	2019-2002
Pile Load Test Report	N.A.
PDA Report	Dynamic Testing of Piles, Highway 404 Overpass at 16th Avenue, North Abutment, December 15, 2020 Visit, MTO Contract No. 2019-2002, Project No. BRM-00607443-A0 (EXP), Dec. 17, 2020
PDA Report	Dynamic Testing of Piles, Highway 404 Overpass at 16th Avenue, South Abutment, February 06 and 10, 2020 Visit, Project No. BRM-00607443-A0 (EXP), Feb. 12, 2020
PDA Report	PDA Field Report (EXP). Hwy. 404 Overpass at 16th Avenue, North Abutment, Project No. BRM-00607443-A0 (Aug. 19, 2021)
PDA Report	PDA Field Report (EXP). Hwy. 404 Overpass at 16th Avenue, Pier, Project No. BRM-00607443-A0 (Aug. 20, 2021)
PDA Report	PDA Field Report (EXP). Hwy. 404 Overpass at 16th Avenue, Soith Abutment & Pier, Project No. BRM-00607443-A0 (Aug. 23, 2021)
PDA Report	PDA Field Report (EXP). Hwy. 404 Overpass at 16th Avenue, Soith Abutment & Pier, Project No. BRM-00607443-A0 (Aug. 26, 2021)
Pile Logs	No official report, only unsorted files were provided.

Pile I.D.	Soil Stratum	Pile Type
NA-P2 (Vert.)	Cohesive	Friction
NA-P3 (Vert.)	Cohesive	Friction
NA-P6 (Vert.)	Cohesive	Friction
NA-P7 (Vert.)	Cohesive	Friction
S23 (Vert.)	Cohesionless	End Bearing
S26 (Vert.)	Cohesionless	End Bearing
S27 (Vert.)	Cohesionless	End Bearing
S24 (Vert.)	Cohesionless	End Bearing
S26 (Vert.)	Cohesionless	End Bearing
S23 (Vert.)	Cohesionless	End Bearing
NAP-301 (Vert.)	Cohesive	Friction
NAP-302 (Vert.)	Cohesive	Friction
NAP-308 (Vert.)	Cohesive	Friction
NAP-307 (Vert.)	Cohesive	Friction
P20 (B1:8)	Layered	Friction
P21 (B1:8)	Layered	Friction
P23 (B1:8)	Layered	Friction
SA-P311 (Vert.)	Cohesive	End Bearing
SA-P307 (Vert.)	Cohesionless	End Bearing
SA-P303 (Vert.)	Cohesionless	End Bearing
Pier-P29 (B1:8)	Cohesive	End Bearing
SA-P314 (Vert.)	Cohesionless	End Bearing
Pier-P14 (B1:8)	Cohesive	End Bearing
Pier-P8 (B1:8)	Cohesve	End Bearing



Pile Design Capacity per FIDR (kN)	
Factored ULS	SLS for 25 mm Settlement
1400	1200

Vert. Vertical Pile
EOID: End of Initial Drive
BOR: Beginning of Restrike
B1:8 Battered at 8 Vertical to 1 Horizontal

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice location from bottom of pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
NA-P2 (Vert.)	North Abutment	HP310 x 110	39.62	-	33	42.8	Yes	19.81	189.2	156.2
NA-P3 (Vert.)	North Abutment		39.62	-	29.8	42.8	Yes	19.81	189	159.2
NA-P6 (Vert.)	North Abutment		39.62	-	31.2	42.8	Yes	19.81	189	157.8
NA-P7 (Vert.)	North Abutment		39.62	-	31	42.8	Yes	19.81	189	158
S23 (Vert.)	South Abutment		34.7	-	30.2	37.4	Yes	13.74/27.9	190.4	160.2
S26 (Vert.)	South Abutment		40	-	29.7	43.2	Yes	13.9/26.92	190.3	160.6
S27 (Vert.)	South Abutment		40	-	29.5	43.2	Yes	13.82/27.55	190.4	160.9
S24 (Vert.)	South Abutment		35.02	-	30	37.8	Yes	13.85/27.22	190.3	160.3
S26 (Vert.)	South Abutment		40	-	29.7	43.2	Yes	13.9/26.92	190.3	160.6
S23 (Vert.)	South Abutment		34.7	-	30.2	37.4	Yes	13.74/27.9	190.4	160.2
NAP-301 (Vert.)	North Abutment		35.2	-	31	38.0	Yes	16.85	189	158
NAP-302 (Vert.)	North Abutment		36.74	-	29.1	39.6	Yes	18.40	188.9	159.8
NAP-308 (Vert.)	North Abutment		38.76	-	29.6	41.8	Yes	18.88	188.8	159.2
NAP-307 (Vert.)	North Abutment		38.3	-	30	41.3	Yes	18.39	189	159
P20 (B1:8)	Pier		36.74	-	27.6	39.6	Yes	16.83	188.2	160.6
P21 (B1:8)	Pier		36.71	-	28.1	39.6	Yes	16.81	188.3	160.2
P23 (B1:8)	Pier		35.24	-	30	38.0	Yes	16.86	188.2	158.2
SA-P311 (Vert.)	South Abutment		38.17	-	31.7	41.2	Yes	18.32	187.6	155.9
SA-P307 (Vert.)	South Abutment		38.76	-	29.8	41.8	Yes	18.86	187.7	157.9
SA-P303 (Vert.)	South Abutment		38.27	-	28.9	41.3	Yes	18.39	187.6	158.7
Pier-P29 (B1:8)	Pier		36.75	-	33	39.7	Yes	16.83	188.3	155.3
SA-P314 (Vert.)	South Abutment		38.05	-	29.6	41.1	Yes	18.29	187.5	157.9
Pier-P14 (B1:8)	Pier		39.6	-	32.2	42.7	Yes	19.8	188.5	156.3
Pier-P8 (B1:8)	Pier		39.6	-	33	42.7	Yes	19.8	188.3	155.3

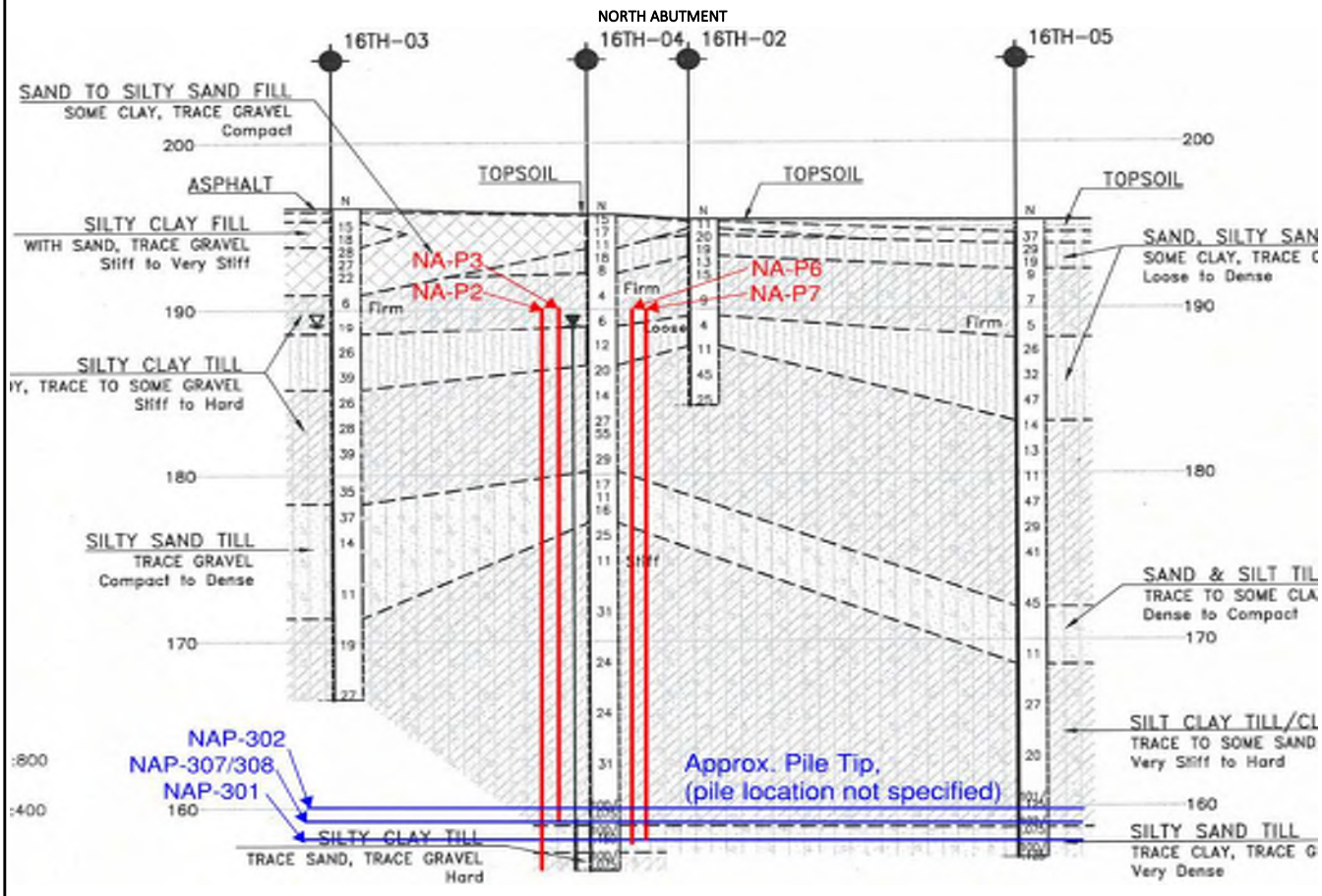
Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
NA-P2 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	600	No	110	Excavator or Crane	Fixed	Dec. 15, 2020
NA-P3 (Vert.)					No				Dec. 15, 2020
NA-P6 (Vert.)					No				Dec. 11, 2020
NA-P7 (Vert.)					No				Dec. 11, 2020
S23 (Vert.)	Berminghammer B-21	Diesel Hammer	2100	600	No	72			Feb. 6, 2020
S26 (Vert.)					No				Jan. 30, 2020
S27 (Vert.)	EML45	(10,000lb Drop Hammer; Drop Height = 1.8 m)	4536	408	Yes	81			Feb. 10, 2020
S24 (Vert.)					Yes				Feb. 10, 2020
S26 (Vert.)					Yes				Jan. 30, 2020
S23 (Vert.)					Yes				Feb. 6, 2020
NAP-301 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	600	No	110			Aug. 18, 2021
NAP-302 (Vert.)					No				Aug. 18, 2021
NAP-308 (Vert.)					No				Aug. 20, 2021
NAP-307 (Vert.)					No				Aug. 20, 2021
P20 (B1:8)					No				Aug. 18, 2021
P21 (B1:8)					No				Aug. 18, 2021
P23 (B1:8)					No				Aug. 18, 2021
SA-P311 (Vert.)					No				Aug. 20, 2021
SA-P307 (Vert.)					No				Aug. 21, 2021
SA-P303 (Vert.)					No				Aug. 23, 2021
Pier-P29 (B1:8)					No				Aug. 23, 2021
SA-P314 (Vert.)					No				Aug. 26, 2021
Pier-P14 (B1:8)					No				Aug. 26, 2021
Pier-P8 (B1:8)					No				Aug. 26, 2021

Pile No.	Hiley Test Results			Pile Driving Analyzer Data							
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
NA-P2 (Vert.)	Dec. 15, 2020	EOID	3751	Dec. 15, 2020	EOID	250	44	37	40	224	3500
NA-P3 (Vert.)	Dec. 15, 2020	EOID	4294	Dec. 15, 2020	EOID	64	33	39	30.0	204	3300
NA-P6 (Vert.)	Dec. 15, 2020	BOR	4512	Dec. 15, 2020	BOR	450	40	37	36.4	217	3600
NA-P7 (Vert.)	Dec. 15, 2020	BOR	4512	Dec. 15, 2020	BOR	450	39	38	35.5	211	3500
S23 (Vert.)	Feb. 6, 2020	EOID	5516	Feb. 6, 2020	EOID	13	26	35	36.1	210	1800
S26 (Vert.)	Feb. 6, 2020	BOR	3303	Feb. 6, 2020	BOR	63	22	37	30.6	187	2250
S27 (Vert.)	Feb. 10, 2020	EOID	2937	Feb. 10, 2020	EOID	21	58	-	71.6	240	2900
S24 (Vert.)	Feb. 10, 2020	EOID	2832	Feb. 10, 2020	EOID	19	58	-	71.6	224	2900
S26 (Vert.)	Feb. 10, 2020	BOR	2834	Feb. 10, 2020	BOR	63	52	-	64.2	207	3000
S23 (Vert.)	Feb. 10, 2020	BOR	2838	Feb. 10, 2020	BOR	18	56	-	69.1	222	2900
NAP-301 (Vert.)	Aug. 19, 2021	BOR	7170	Aug. 19, 2021	BOR	>100	54	34	49.1	282	4400
NAP-302 (Vert.)	Aug. 19, 2021	BOR	5601	Aug. 19, 2021	BOR	>100	37	38	33.6	230	3600
NAP-308 (Vert.)	Aug. 19, 2021	EOID	4339	Aug. 19, 2021	EOID	25	41	37	37.3	253	3100
NAP-307 (Vert.)	Aug. 19, 2021	EOID	4171	Aug. 19, 2021	EOID	13	52	35	47.3	276	3200
P20 (B1:8)	Aug. 20, 2021	BOR	4670	Aug. 20, 2021	BOR	11	41	36	37.3	247	3000
P21 (B1:8)	Aug. 20, 2021	BOR	4671	Aug. 20, 2021	BOR	11	40	36	36.4	243	3050
P23 (B1:8)	Aug. 20, 2021	BOR	4530	Aug. 20, 2021	BOR	22	47	36	42.7	265	3300
SA-P311 (Vert.)	Aug. 23, 2021	BOR	3903	Aug. 23, 2021	BOR	80	61	34	55.5	290	4400
SA-P307 (Vert.)	Aug. 23, 2021	BOR	4096	Aug. 23, 2021	BOR	100	41	38	37.3	245	3800
SA-P303 (Vert.)	Aug. 23, 2021	EOID	4788	Aug. 23, 2021	EOID	11	41	38	37.3	242	3200
Pier-P29 (B1:8)	Aug. 23, 2021	EOID	4311	Aug. 23, 2021	EOID	18	49	35	44.5	263	3600
SA-P314 (Vert.)	Aug. 26, 2021	EOID	4775	Aug. 26, 2021	EOID	18	41	39	37.3	248	3200
Pier-P14 (B1:8)	Aug. 26, 2021	EOID	4583	Aug. 26, 2021	EOID	25	40	38	36.4	242	3600
Pier-P8 (B1:8)	Aug. 26, 2021	EOID	4583	Aug. 26, 2021	EOID	25	39	38	35.5	242	3700

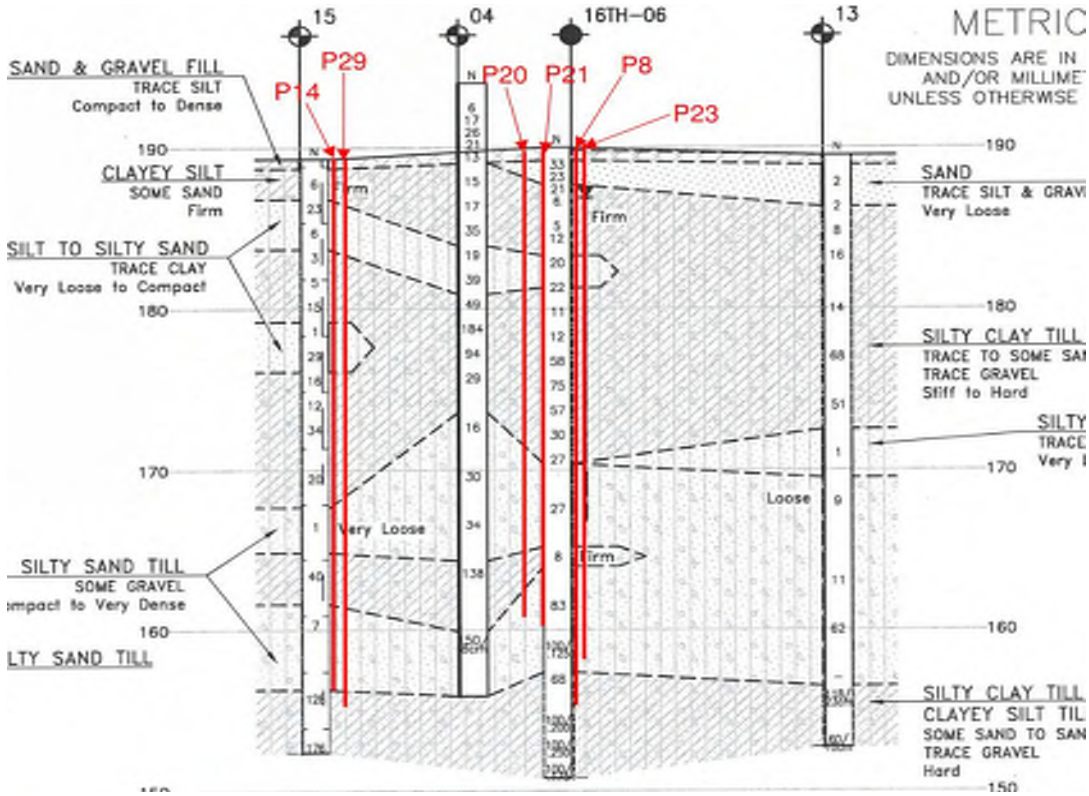
CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
NA-P2 (Vert.)	-	-	-	-	-	-	-	-
NA-P3 (Vert.)	EOID	-	2075	63	1225	37	3300	Friction
NA-P6 (Vert.)	BOR	-	3200	89	400	11	3600	Friction
NA-P7 (Vert.)	-	-	-	-	-	-	-	-
S23 (Vert.)	-	-	-	-	-	-	-	-
S26 (Vert.)	-	-	-	-	-	-	-	-
S27 (Vert.)	-	-	-	-	-	-	-	-
S24 (Vert.)	EOID	10/13	1025	35	1875	65	2900	End Bearing
S26 (Vert.)	-	-	-	-	-	-	-	-
S23 (Vert.)	BOR	10/14	1075	37	1825	63	2900	End Bearing
NAP-301 (Vert.)	-	-	-	-	-	-	-	-
NAP-302 (Vert.)	-	-	-	-	-	-	-	-
NAP-308 (Vert.)	-	-	-	-	-	-	-	-
NAP-307 (Vert.)	-	-	-	-	-	-	-	-
P20 (B1:8)	-	-	-	-	-	-	-	-
P21 (B1:8)	-	-	-	-	-	-	-	-
P23 (B1:8)	-	-	-	-	-	-	-	-
SA-P311 (Vert.)	-	-	-	-	-	-	-	-
SA-P307 (Vert.)	-	-	-	-	-	-	-	-
SA-P303 (Vert.)	-	-	-	-	-	-	-	-
Pier-P29 (B1:8)	-	-	-	-	-	-	-	-
SA-P314 (Vert.)	-	-	-	-	-	-	-	-
Pier-P14 (B1:8)	-	-	-	-	-	-	-	-
Pier-P8 (B1:8)	-	-	-	-	-	-	-	-

Soil Stratigraphy at Pile Locations

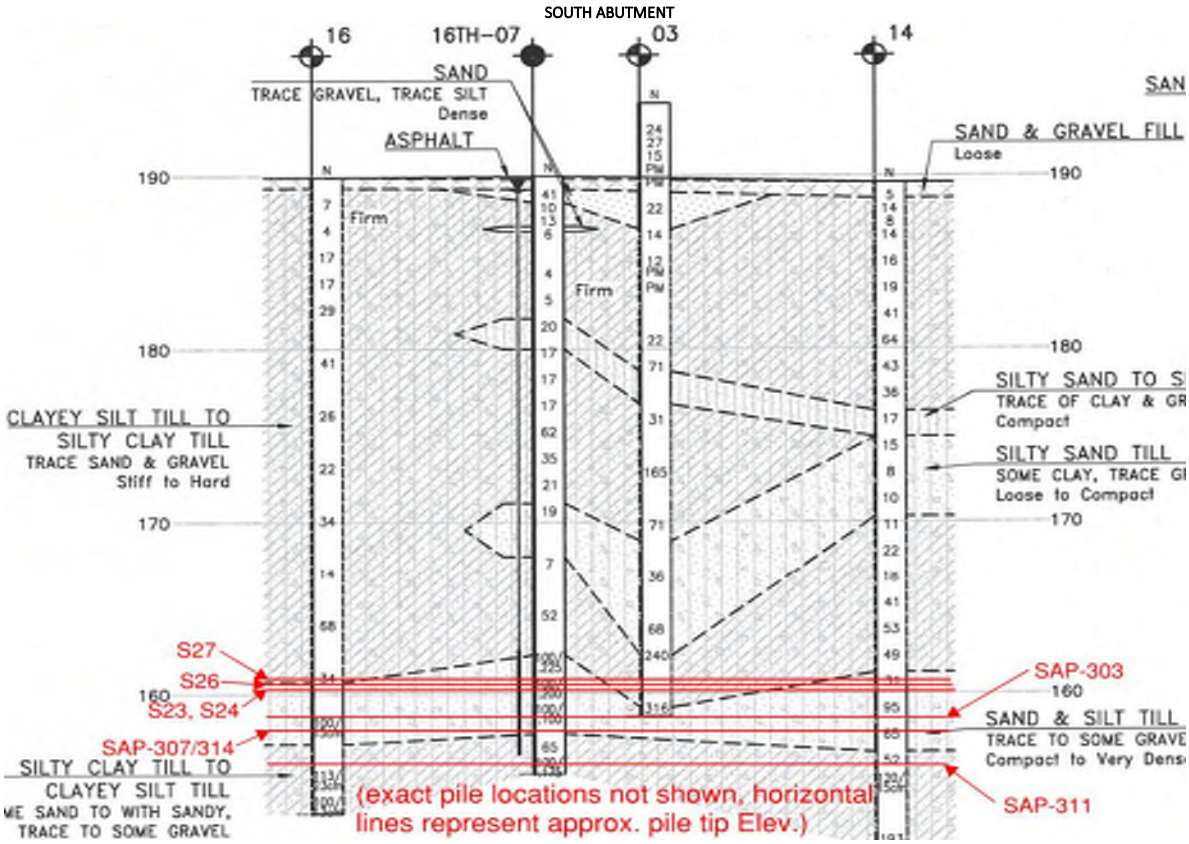
Note: Where specific pile location show below, it is approximate.



PIER



SOUTH ABUTMENT



Site No:	11	Project:	Hwy 404 HOV Lane Expansion & Rehab (Rouge River)	Pile Load Test	No
				PDA Test	Yes
				Hiley Test	Yes

Document Type	Document Title
FIDR	Rouge River NBL and SBL Bridges, Replacement and Widening, Highway 404 HOV Lane Expansion and Rehabilitation, Contract 2, Markham Ontario, Site 37-347/1 and 34/347/2, G.W.P. 2930-17-00, Geocres. 30M14-485 (Jan. 23, 2019)
Contract Dwgs	2019-2002
Pile Load Test Report	N.A.
PDA Report	PDA Field Report (EXP), Hwy. 404 Rouge River Bridge Replacement, North Abutment, Project No. BRM-00607283-A0, Oct. 23, 2019
PDA Report	PDA Field Report (EXP), Hwy. 404 Rouge River Bridge Replacement, South Abutment, Project No. BRM-00607283-A0, Dec. 4, 2019
PDA Report	PDA Field Report (EXP), Hwy. 404 Rouge River Bridge Replacement, South Abutment, Project No. BRM-00607283-A0, Oct. 19, 2020
PDA Report	PDA Field Report (EXP), Hwy. 404 Rouge River Bridge Replacement, South Abutment, Project No. BRM-00607283-A0, Oct. 8, 2021
Pile Logs	No official report, only unsorted files were provided.

Pile I.D.	Soil Stratum	Pile Type
N11 (Vert.)	Cohesive	End Bearing
N26 (Vert.)	Cohesive	End Bearing
N24 (Vert.)	Cohesive	End Bearing
N25 (Vert.)	Cohesive	End Bearing
N13 (Vert.)	Cohesive	End Bearing
N22 (Vert.)	Cohesive	End Bearing
S24 (Vert.)	Cohesive	End Bearing
S23 (Vert.)	Cohesive	End Bearing
S17 (Vert.)	Cohesive	End Bearing
S19 (Vert.)	Cohesive	End Bearing
S18 (Vert.)	Cohesive	End Bearing
S35 (Vert.)	Cohesive	End Bearing
S34 (Vert.)	Cohesive	End Bearing
S33 (Vert.)	Cohesive	End Bearing
SA9 (Vert.)	Cohesive	End Bearing
SA4 (Vert.)	Cohesive	End Bearing
SA11 (Vert.)	Cohesive	End Bearing
SA2 (Vert.)	Cohesive	End Bearing

Vert.	Vertical Pile
EOID:	End of Initial Drive
BOR:	Beginning of Restrike
DD:	During Driving

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Location from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
N11 (Vert.)	North Abut. (SBL)	HP360 x 174	16.8	-	14.9	28.7	Titus Steel Standard H-Points	-	198.1	183.2
N26 (Vert.)	North Abut. (NBL)		15.95	-	12.2	27.2		-	198.3	186.1
N24 (Vert.)	North Abut. (NBL)		15.7	-	12.2	26.8		-	198.1	185.9
N25 (Vert.)	North Abut. (NBL)		16.85	-	12.4	28.8		-	198.3	185.9
N13 (Vert.)	North Abut. (SBL)		20.75	-	15.2	35.4		16.8	198	182.8
N22 (Vert.)	North Abut. (NBL)		15.7	-	13.2	26.8		-	197.3	184.1
S24 (Vert.)	South Abut. (NBL)		17.4	-	13.9	29.7		-	197.3	183.4
S23 (Vert.)	South Abut. (NBL)		17.4	-	13.9	29.7		-	197.6	183.7
S17 (Vert.)	South Abut. (SBL)		17.45	-	14.5	29.8		-	197.4	182.9
S19 (Vert.)	South Abut. (SBL)		17.5	-	14.5	29.9		-	197.4	182.9
S18 (Vert.)	South Abut. (SBL)		17.5	-	14.5	29.9		-	197.4	182.9
S35 (Vert.)	South Abut. (NBL)		15.2	-	12.4	25.9		-	197.3	186.1
S34 (Vert.)	South Abut. (NBL)		15.2	-	12.4	25.9		-	197.3	185.7
S33 (Vert.)	South Abut. (NBL)		15.2	-	12.4	25.9		-	197.3	185.7
SA9 (Vert.)	South Abut. (SBL)		20.98	-	15.2	35.8		12.23	198	180
SA4 (Vert.)	South Abut. (SBL)		21.21	-	15.2	36.2		10.69	198	180
SA11 (Vert.)	South Abut. (SBL)		19.14	-	14.2	32.7		10.68	198	181
SA2 (Vert.)	South Abut. (SBL)		21.59	-	15.2	36.9		10.86	198	179.8

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
N11 (Vert.)	EML45	(10,000lb Drop Hammer; Drop Height = 1.8 m)	4536	408.2	Yes	80.26	Excavator or Crane	Fixed	Oct. 21, 2019
N26 (Vert.)					Yes				Oct. 21, 2019
N24 (Vert.)					Yes				Oct. 23, 2019
N25 (Vert.)					Yes				Oct. 23, 2019
N13 (Vert.)					Yes				Oct. 23, 2019*
N22 (Vert.)					Yes				Oct. 23, 2019
S24 (Vert.)	Berminghammer B-21	Diesel Hammer	2100	600	No	72			Dec. 4, 2019
S23 (Vert.)					No				Dec. 4, 2019
S17 (Vert.)					No				Nov. 29, 2019
S19 (Vert.)					No				Nov. 28, 2019
S18 (Vert.)					No				Nov. 28, 2019
S35 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	600	No	110			Oct. 16, 2020
S34 (Vert.)					No				Oct. 16, 2020
S33 (Vert.)					No				Oct. 16, 2020
SA9 (Vert.)	Berminghammer B-21	Diesel Hammer	2100	600	No	72			Oct. 8, 2021
SA4 (Vert.)					No				Oct. 8, 2021
SA11 (Vert.)					No				Oct. 6, 2021
SA2 (Vert.)					No				Oct. 6, 2021

	Hiley Test Results			Pile Driving Analyzer Data							
Pile No.	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/ 25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
N11 (Vert.)	Oct. 21, 2019	EOID	3919	Oct. 23, 2019	BOR	11.4	44	-	54.8	177	3600
N26 (Vert.)	Oct. 23, 2019	BOR	3671	Oct. 23, 2019	BOR	11.4	42	-	52.3	176	3500
N24 (Vert.)	Oct. 23, 2019	EOID	3454	Oct. 23, 2019	EOID	8.1	47	-	58.6	178	3300
N25 (Vert.)	Oct. 23, 2019	EOID	3910	Oct. 23, 2019	EOID	11.9	46	-	57.3	186	3600
N13 (Vert.)	Oct. 23, 2019	EOID	2230	Oct. 23, 2019	EOID	1.4	47	-	58.6	178	<1000
N22 (Vert.)	Oct. 23, 2019	DD	2900	Oct. 23, 2019	DD	5.7	42	-	52.3	147	2800
S24 (Vert.)	Dec. 4, 2019	EOID	7573	Dec. 4, 2019	EOID	18.0	23	37	31.9	183	3300
S23 (Vert.)	Dec. 4, 2019	EOID	5709	Dec. 4, 2019	EOID	17.0	23	37	31.9	192	3300
S17 (Vert.)	Dec. 4, 2019	BOR	7254	Dec. 4, 2019	BOR	18.0	25	36	34.7	190	3300
S19 (Vert.)	Dec. 4, 2019	BOR	5378	Dec. 4, 2019	BOR	9.0	24	37	33.3	182	2300
S18 (Vert.)	Dec. 4, 2019	BOR	5890	Dec. 4, 2019	BOR	11.0	23	37	31.9	175	2800
S35 (Vert.)	Oct. 19, 2020	BOR	6532	Oct. 19, 2020	BOR	7.1	41	37	37.3	206	2900
S34 (Vert.)	Oct. 19, 2020	BOR	4505	Oct. 19, 2020	BOR	4.2	39	38	35.5	211	2500
S33 (Vert.)	Oct. 19, 2020	BOR	8166	Oct. 19, 2020	BOR	20.0	39	38	35.5	219	3800
SA9 (Vert.)	Oct. 8, 2021	EOID	4144	Oct. 8, 2021	EOID	8	31	35	43.1	222	2800
SA4 (Vert.)	Oct. 8, 2021	EOID	5855	Oct. 8, 2021	EOID	25	30	34	41.7	212	3400
SA11 (Vert.)	Oct. 8, 2021	BOR	4239	Oct. 8, 2021	BOR	8	28	35	38.9	208	2800
SA2 (Vert.)	Oct. 8, 2021	BOR	5829	Oct. 8, 2021	BOR	25	27	35	37.5	204	3400

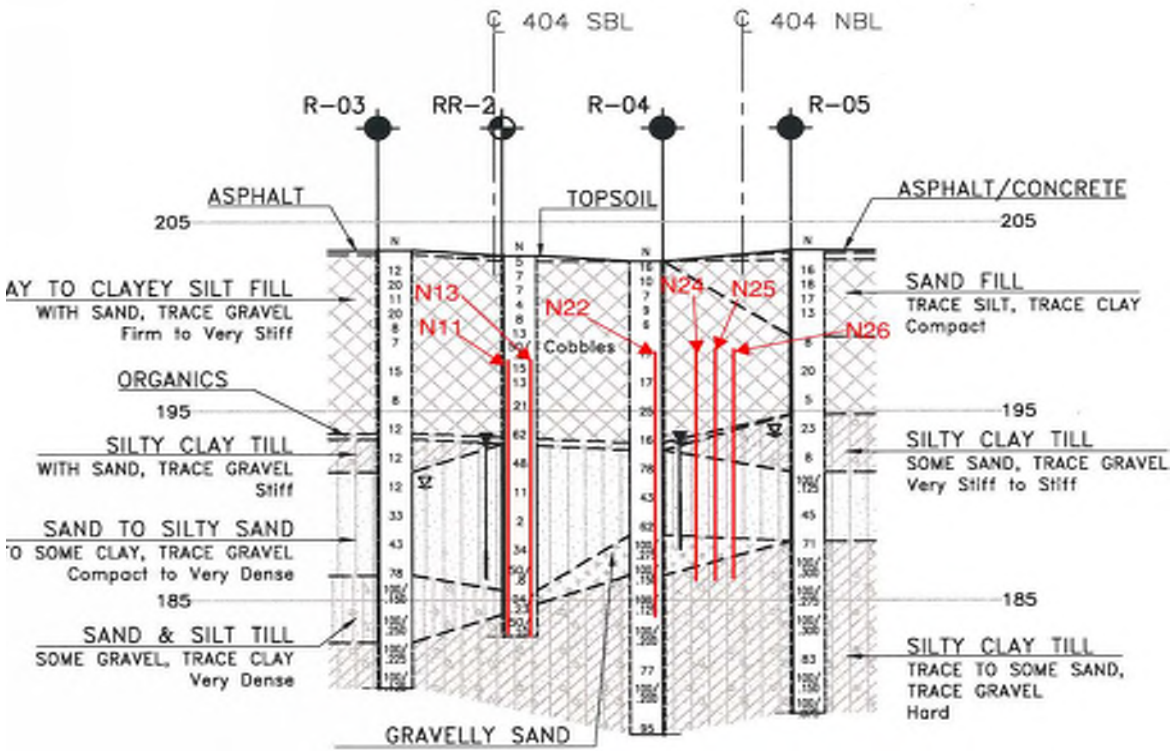
CAPWAP									Pile Design Capacity, FIDR (kN)	
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type	Factored ULS	SLS (25 mm settlement)
No CAPWAP Data Available									1600	1400

*Note Pile Redriven at a later date, no PDA test data available

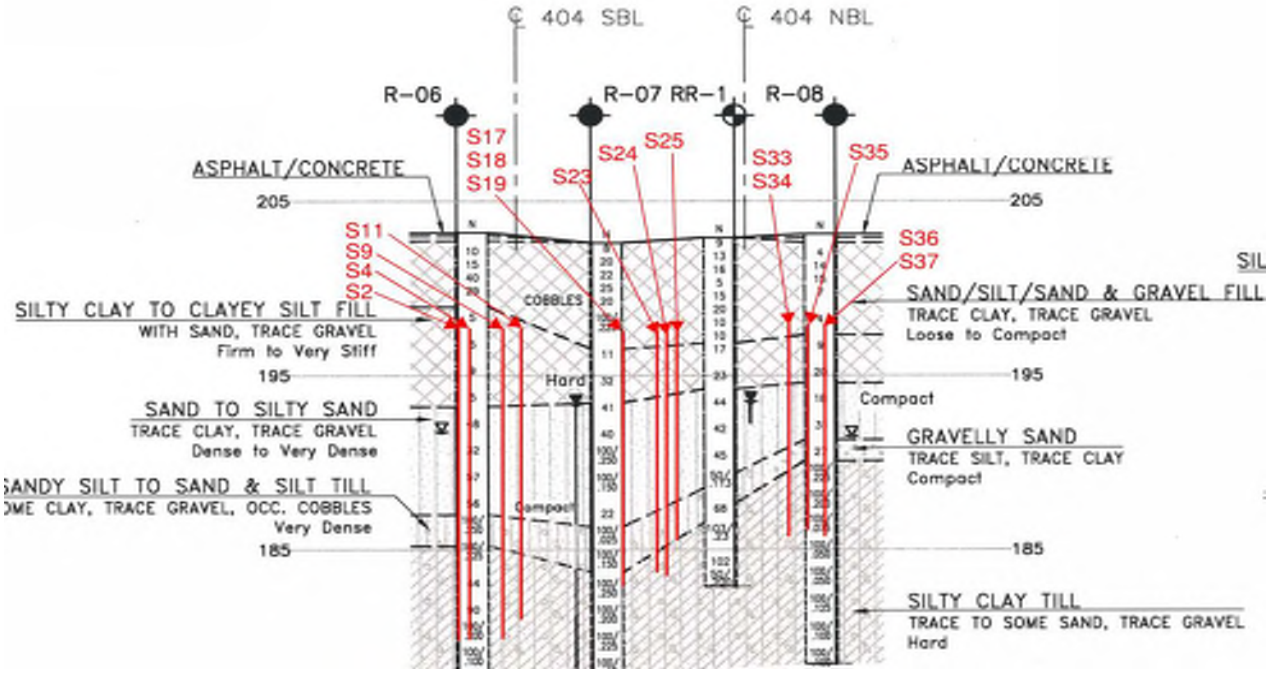
Soil Stratigraphy at Pile Locations

Note: Pile Locations Shown are Approximate

NORTH ABUTMENT



SOUTH ABUTMENT

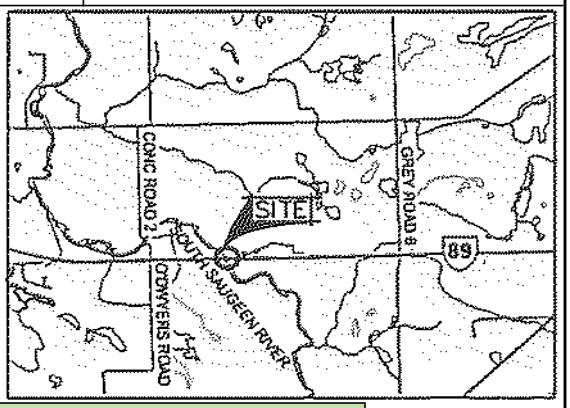


Site No:	12	Project:	South Saugeen River Bridge Replacement, Highway 89

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

FIDR	Contract Drawings	Pile Load Test	Pile Logs/PDA Reports
Foundation and Investigation Report, South Saugeen River Bridge Replacement, Highway 89, West of Mount Forest, ON, MTO Site No. 35-5, G.W.P. 3093-12-00, Geocres No. 40P15-49	2018-4011	N.A.	Stantec. Pile Installation Summary, South Saugeen River Strucuture Replacement 3.0 km West of Mount Forest, Highway 89, MTO Contract No. 2019-3010, Mount Forest, Ontario (Golder, Feb. 5, 2021) Unsorted Pile Driving Records Also Provided

Pile I.D.	Soil Stratum	Pile Type	Event
P4 (vert.)	Cohesionless	Friction/End Bearing	EOID
P4 (vert.)	Cohesionless	Friction/End Bearing	BOR
P9 (vert.)	Cohesionless	Friction/End Bearing	EOID (Tip @ 371.5)
P9 (vert.)	Cohesionless	End Bearing	EOID (Tip @ 370.7)
P14 (vert.)	Cohesive	End Bearing	EOID, BOR
P19 (vert.)	Cohesive	End Bearing	EOID, BOR



EOID: End of Initial Drive
BOR: Beginning of Restrike
Vert. Pile is Vertical

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Location from Bott. of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
P4 (vert.)	East Abutment	HP12 x 74	10.67	-	9.1	11.5	Titus "H" Bearing Points (Standard Model)	-	381.1	372
	East Abutment		10.67	-	9.2	11.5		-	381.1	371.9
P9 (vert.)	East Abutment		10.75	-	9.6	11.6		10.67	381.1	371.5
	East Abutment		10.75	-	10.4	11.6		10.67	381.1	370.7
P14 (vert.)	West Abutment		10.67	-	9.4	11.5		-	381.3	371.9
	West Abutment		10.67	-	9.6	11.5		-	381.3	371.7
P19 (vert.)	West Abutment		10.67	-	9.8	11.5		-	381.3	371.5
	West Abutment		10.67	-	9.9	11.5		-	381.3	371.4

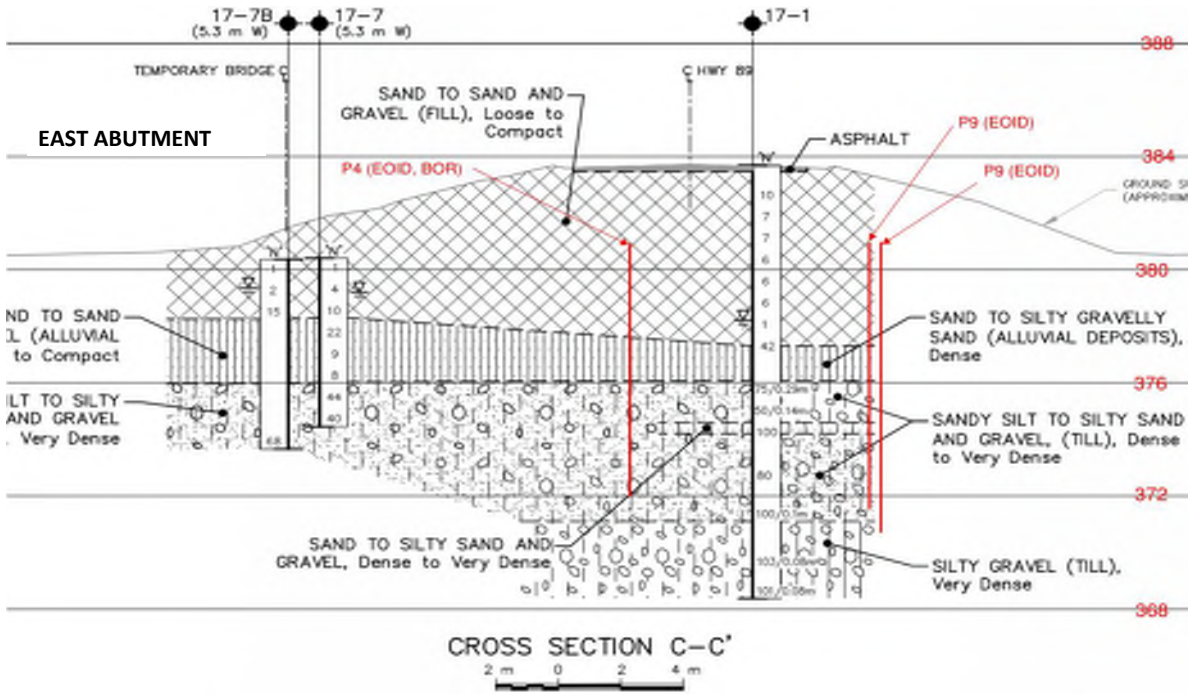
Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
P4 (vert.)	Delmag D19-42	Diesel Hammer	1820	755	No	66	Crane	Fixed	Jun. 8, 2020
					No				
P9 (vert.)					No				Jun. 8/ Jun. 10, 2020
					No				
P14 (vert.)					No				Jun. 15, 2020
					No				
P19 (vert.)					No				Jun. 15, 2020
					No				

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	ETR (%)	FMX (kN)	CSX (Mpa)	CSB (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
P4 (vert.)	Jun. 8, 2020	EOID	2380	Jun. 8, 2020	EOID	4.8	29.2	44.2	2861	203	87	1810
	Jun. 9, 2020	BOR	2790	Jun. 9, 2020	BOR	6.3	27.8	42.1	2830	204	108	1870
P9 (vert.)	Jun. 8, 2020	EOID	1870	Jun. 8, 2020	BOR	2.1	25.6	38.8	2621	191	77	1295
	Jun. 10, 2020	EOID	2540	Jun. 10, 2020	EOID	9.1	25.6	38.8	2794	204	139	2270
P14 (vert.)	Jun. 15, 2020	EOID	2720	Jun. 15, 2020	EOID	6.0	31.5	47.7	3094	224	124	1910
	Jun. 16, 2020	BOR	2510	Jun. 16, 2020	BOR	5.2	31.4	47.6	2972	220	102	1905
P19 (vert.)	Jun. 15, 2020	EOID	2580	Jun. 15, 2020	EOID	4.7	28.7	43.5	2958	211	100	1680
	Jun. 16, 2020	BOR	2790	Jun. 16, 2020	BOR	4.6	27.3	41.4	2722	196	105	1690

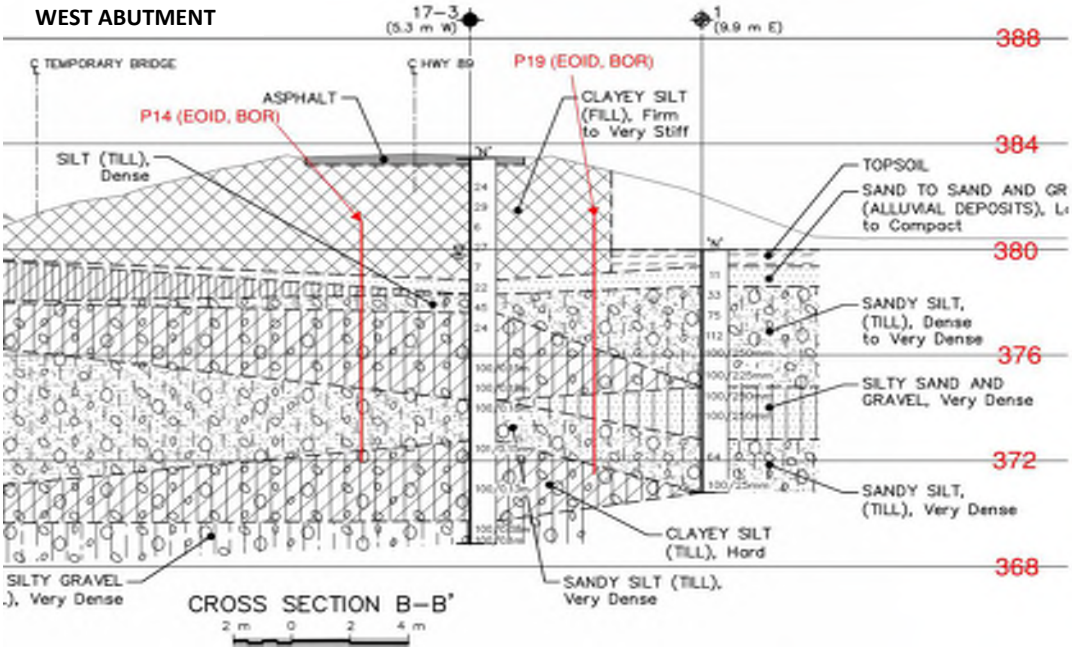
CAPWAP									Pile Design Capacity, FIDR (kN)	
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type	Factored ULS	SLS for 25 mm Settlement
P4 (vert.)	EOID	-	909	50	904	50	1813	Friction	1500*	SLS will exceed ULS therefore ULS governs
	BOR	-	920	49	950	51	1870	End Bearing		
P9 (vert.)	BOR	-	695	54	600	46	1295	Friction		
	EOID	-	793	35	1478	65	2271	End Bearing		
P14 (vert.)	EOID	-	559	29	1348	71	1907	End Bearing		
	BOR	-	501	26	1404	74	1905	End Bearing		
P19 (vert.)	EOID	-	536	32	1144	68	1680	End Bearing		
	BOR	-	550	33	1140	67	1690	End Bearing		

*Note: As per Stantec Pile Installation Summary, design ultimate ULS capacity re-evaluated to 950 kN per pile

Soil Stratigraphy at Pile Locations



CROSS SECTION C–C'



CROSS SECTION B–B'

Site No:	13	Project:	Hwy 400 South Canal Bridges, GWP 2025-13-00	Pile Load Test	Yes
				PDA Test	Yes
				Hiley Test	Yes

Document Type	Document Title
FIDR	South Canal Bridges, Highway 400 Widening from North of King Road to North of South Canal Road, Regional Municipality of York, GWP 2025-13-00, Geocres. No. 31D-556, Report Number: 09-1111 0018-4, Golder (July 2015)
Contract Dwgs	2015-2004
Pile Load Test Report	South Canal Bridges, Highway 400 Widening from North of King Road to North of South Canal Road, Regional Municipality of York, GWP 2025-13-00, Geocres. No. 31D-759, Report Number: 09-1111-0018, Golder (Oct. 5, 2017)
PDA Report	PDA Field Report (EXP). South Canal Bridge, North Abutment, Project No. BRM-00603904-A0 (Aug. 17, 2016)
PDA Report	PDA Field Report (EXP). South Canal Bridge, Pier (SBL), Project No. BRM-00603904-A0 (Sep. 14, 2016)
PDA Report	PDA Field Report (EXP). South Canal Bridge, Pier (SBL), Project No. BRM-00603904-A0 (Sep. 19, 2016)
PDA Report	PDA Field Report (EXP). South Canal Bridge, Pier (SBL), Project No. BRM-00603904-A0 (Sep. 21, 2016)
PDA Report	PDA Field Report (EXP). South Canal Bridge, Project No. BRM-00603904-A0 (Sep. 23, 2016)
PDA Report	PDA Field Report (EXP). South Canal Bridge, Project No. BRM-00603904-A0 (Oct. 4, 2016)
PDA Report	PDA Field Report (EXP). South Canal Bridge, South Abut-SBL, Project No. BRM-00603904-A0 (Oct. 12, 2016)
PDA Report	PDA Field Report (EXP). South Canal Bridge, Pier Stage II, Project No. BRM-00603904-A0 (Oct. 25, 2017)
PDA Report	PDA Field Report (EXP). South Canal Bridge, Pier Stage 3, Project No. BRM-00603904-A0 (Oct. 26, 2017)
Pile Logs	No official report, only unsorted files were provided.

PLT Purpose: Compare PLT to calculated design geotech. resistance and dynamic testing; optimize correlations between theory, dynamic testing, and actual geotech resistance.
PLT Test Methods: ASTM D1143-07 using a modified Procedure A - Quick Test Method, loaded to 2550 kN which is the maximum limit for the reaction system.
PLT Test Termination: Reaction caisson failed at 2200 kN load increment.

Pile Load Tests Results (Separate Location from Bridge Piles)

Test Type	Pile Tip Elev. (m)	Set-up Period (Days)	Ultimate Resistance (kN)	Resistance Factor (CHBDC, 2014)	f-ULS (kN)
Pile Load Test	204.0	0	1700	0.6	1020
PDA Test		258	1100	0.5	550

Pile I.D.	Location	Soil Stratum	Pile Type
Pile Load Test	NE of Bridge	Cohesionless	End Bearing
299 (B1:4)	North Abutment	Cohesionless	End Bearing
304 (B1:4)	North Abutment	Cohesionless	End Bearing
308 (B1:4)	North Abutment	Cohesionless	End Bearing
399 (vert.)	North Abutment	Cohesionless	End Bearing
400 (vert.)	North Abutment	Cohesionless	End Bearing
2 (B1:10)	South Abutment	Cohesive	Friction
33 (B1:4)	South Abutment	Cohesive	Friction
47 (B1:4)	South Abutment	Cohesive	Friction
49 (B1:4)	South Abutment	Cohesive	Friction
53 (B1:4)	South Abutment	Cohesive	Friction
54 (B1:4)	South Abutment	Cohesive	Friction
24 (B1:10)	South Abutment	Layered	Friction
119 (B1:4)	South Abutment	Layered	Friction
136 (B1:4)	South Abutment	Layered	Friction
148 (B1:10)	pier	Cohesive	End Bearing
149 (B1:10)	pier	Cohesive	End Bearing
203 (vert.)	pier	Cohesive	End Bearing
204 (vert.)	pier	Cohesive	End Bearing
206 (vert.)	pier	Cohesive	End Bearing
207 (vert.)	pier	Cohesive	End Bearing
208 (vert.)	pier	Cohesive	End Bearing
261 (B1:10)	pier	Cohesive	End Bearing
262 (B1:10)	pier	Cohesive	End Bearing
224 (vert.)	pier	Cohesionless	End Bearing
226 (vert.)	pier	Cohesionless	End Bearing
227 (vert.)	pier	Cohesionless	End Bearing
279 (B1:10)	pier	Cohesionless	End Bearing
186 (B1:10)	pier	Cohesionless	End Bearing
188 (B1:10)	pier	Cohesionless	End Bearing
242 (vert.)	pier	Cohesionless	End Bearing
296 (B1:10)	pier	Cohesionless	End Bearing

Vert.	Vertical Pile		
EOID	End of Initial Driving		
BOR	Beginning of Restrike		
BO2R	Beginning of 2nd Restrike	B1:#	Battered at # Vertical to 1 Horizontal

Pile Information										
Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Location from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
308 (B1:4)	North Abutment	HP310 x 110	17.4	-	15.75	18.8	Titus 'H' Bearing Pile Points (Standard Model) or Equivalent	-	218.2	202.5
304 (B1:4)	North Abutment		17.4	-	15.65	18.8		-	218.2	202.6
299 (B1:4)	North Abutment		17.4	-	15.6	18.8		-	218.2	202.6
203 (vert.)	Pier (SBL)		14.9	-	13.4	16.1		-	217.8	204.4
204 (vert.)	Pier (SBL)		14.9	-	13.25	16.1		-	217.8	204.6
148 (B1:10)	Pier (SBL)		14.9	-	13.3	16.1		-	217.8	204.5
149 (B1:10)	Pier (SBL)		14.9	-	13.3	16.1		-	217.8	204.5
188 (B1:10)	Pier (NBL)		14.9	-	13.3	16.1		-	217.8	204.5
242 (vert.)	Pier (NBL)		14.9	-	13.3	16.1		-	217.8	204.5
296 (B1:10)	Pier (NBL)		14.9	-	13.3	16.1		-	217.8	204.5
186 (B1:10)	Pier (NBL)		14.9	-	13.3	16.1		-	217.8	204.5
399 (vert.)	North Abutment (NBL)		16.48	-	14.2	17.8		-	218.2	204.0
400 (vert.)	North Abutment (NBL)		16.62	-	14.2	17.9		-	218.2	204.0
24 (B1:10)	South Abutment (NBL)		21	-	18.3	22.7		-	219.4	201.1
119 (B1:4)	South Abutment (NBL)		21	-	19	22.7		-	219.4	200.4
136 (B1:4)	South Abutment (NBL)		21	-	19	22.7		-	219.4	200.4
47 (B1:4)	South Abutment (SBL)		21	-	14.5	22.7		-	219.4	204.9
49 (B1:4)	South Abutment (SBL)		21	-	16	22.7		-	219.4	203.4
53 (B1:4)	South Abutment (SBL)		21	-	19	22.7		-	219.4	200.4
54 (B1:4)	South Abutment (SBL)		21	-	19	22.7		-	219.4	200.4
2 (B1:10)	South Abutment (SBL)		21	-	19.2	22.7		-	219.4	200.2
33 (B1:4)	South Abutment (SBL)		21	-	18.6	22.7		-	219.4	200.8
206 (vert.)	Pier		14.9	-	13.3	16.1		-	217.8	204.5
208 (vert.)	Pier		14.9	-	13.3	16.1		-	217.8	204.5
207 (vert.)	Pier		14.9	-	13.3	16.1		-	217.8	204.5
261 (B1:10)	Pier		14.9	-	13.3	16.1		-	217.8	204.5
262 (B1:10)	Pier		14.9	-	13.3	16.1		-	217.8	204.5
227 (vert.)	Pier		14.9	-	13.4	16.1		-	217.8	204.4
226 (vert.)	Pier		14.9	-	13.3	16.1		-	217.8	204.5
224 (vert.)	Pier		14.9	-	13.4	16.1		-	217.8	204.4
279 (B1:10)	Pier		14.9	-	13.4	16.1		-	217.8	204.4

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
308 (B1:4)	Liebherr H40/4	Hydraulic Hammer	4000	Note 1	No	30	Note 2	Note 2	Note 3
304 (B1:4)					No				Note 3
299 (B1:4)					No				Note 3
203 (vert.)	Delmag D30-32	Diesel Hammer	3000	620	No	95			Sep. 14, 2016
204 (vert.)					No				Sep. 14, 2016
148 (B1:10)					No				Note 3
149 (B1:10)					No				Note 3
188 (B1:10)	Pileco D30-32	Diesel Hammer	3000	back calculated to about 900	No	95			Note 3
242 (vert.)					No				Note 3
296 (B1:10)					No				Note 3
186 (B1:10)					No				Note 3
399 (vert.)					No				Note 3
400 (vert.)					No				Note 3
24 (B1:10)					No				Note 3
119 (B1:4)					No				Note 3
136 (B1:4)					No				Note 3
47 (B1:4)	Delmag D30-32	Diesel Hammer	3000	620	No	95			Note 3
49 (B1:4)					No				Note 3
53 (B1:4)					No				Note 3
54 (B1:4)					No				Note 3
2 (B1:10)	Delmag D30-32	Diesel Hammer	3000	620	No	95			Note 3
33 (B1:4)					No				Note 3
206 (vert.)	Pileco D30-32	Diesel Hammer	3000	back calculated to about 900	No	95			Oct. 24, 2017
208 (vert.)					No				Oct. 20, 2017
207 (vert.)					No				Oct. 20, 2017
261 (B1:10)					No				Oct. 20, 2017
262 (B1:10)					No				Oct. 20, 2017
227 (vert.)					No				Oct. 20, 2017
226 (vert.)					No				Oct. 23, 2017
224 (vert.)					No				Oct. 23, 2017
279 (B1:10)					No				Oct. 23, 2017

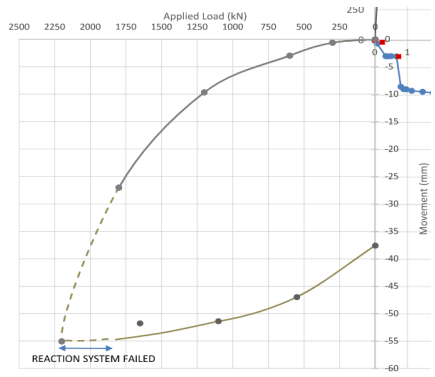
Note 1: Weight of anvil not provided in pile logs.
Note 2: Pile driving equipment and lead not stated in pile logs. Assumed to be crane/fixed lead.
Note 3: Pile Installation Date Not Recorded in Any Provided Documents

Hiley Test Results				Pile Driving Analyzer Data								
Pile No.	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
308 (B1:4)	Aug. 17, 2016	BO2R	1400	Aug. 17, 2016	BO2R	10	15	-	50.0	1630	116	1400
304 (B1:4)	Aug. 17, 2016	BO2R	1800	Aug. 17, 2016	BO2R	14.7	17	-	56.7	1800	127	1800
299 (B1:4)	Aug. 17, 2016	BO2R	1600	Aug. 17, 2016	BO2R	7.6	20	-	66.7	2000	142	1600
203 (vert.)	Sep. 15, 2016	BOR	2345	Sep. 14, 2016	EOID	2	-	-	-	-	-	1400
204 (vert.)	Sep. 15, 2016	BOR	2381	Sep. 14, 2016	EOID	2.9	-	-	-	-	-	1800
148 (B1:10)	Sept. 19, 2016	BOR	3119	Sept. 19, 2016	BOR	4	-	-	-	-	-	2800
149 (B1:10)	Sept. 19, 2016	BOR	2926	Sept. 19, 2016	BOR	4.8	-	-	-	-	-	2900
188 (B1:10)	Sept. 21, 2016	BOR	3607	Sept. 21, 2016	BOR	5.2	-	-	-	-	-	3600
242 (vert.)	Sept. 21, 2016	BOR	3604	Sept. 21, 2016	BOR	8	-	-	-	-	-	3700
296 (B1:10)	Sept. 21, 2016	BOR	2729	Sept. 21, 2016	BOR	3.7	-	-	-	-	-	3000
186 (B1:10)	Sept. 23, 2016	BOR	4102	Sept. 23, 2016	BOR	9.6	44	36	46.3	3750	266	4000
399 (vert.)	Sept. 23, 2016	BOR	1650	Sept. 23, 2016	BOR	13.9	19	46	20.0	1910	135	1650
400 (vert.)	Sept. 23, 2016	BOR	1500	Sept. 23, 2016	BOR	6.1	26	39	27.4	2400	170	1500
24 (B1:10)	Sept. 28, 2016	BOR	4258	Sept. 28, 2016	BOR	27.8	53	35	55.8	3950	280	4100
119 (B1:4)	Sept. 28, 2016	BOR	4488	Sept. 28, 2016	BOR	11.4	53	35	55.8	3640	258	3200
136 (B1:4)	Sept. 28, 2016	BOR	3413	Sept. 28, 2016	BOR	35.7	42	37	44.2	3230	229	4500
47 (B1:4)	Oct. 4, 2016	BOR	1808	Oct. 4, 2016	BOR	4	54	35	56.8	3830	272	1500
49 (B1:4)	Oct. 4, 2016	BOR	2200	Oct. 4, 2016	BOR	5	52	35	54.7	3710	263	1800
53 (B1:4)	Oct. 4, 2016	BOR	3277	Oct. 4, 2016	BOR	23	39	39	41.1	3140	223	3800
54 (B1:4)	Oct. 4, 2016	BOR	3938	Oct. 4, 2016	BOR	31	39	40	41.1	2960	210	3900
2 (B1:10)	Oct. 11, 2016	BOR	3785	Oct. 12, 2016	BOR	8	34	39	35.8	2920	207	2700
33 (B1:4)	Oct. 11, 2016	BOR	3692	Oct. 12, 2016	BOR	7	37	40	38.9	3060	217	2150
206 (vert.)	Oct. 25, 2017	BOR	2507	Oct. 25, 2017	BOR	1.4	51	38	53.7	3540	251	2000
208 (vert.)	Oct. 25, 2017	BOR	3080	Oct. 25, 2017	BOR	2.4	50	36	52.6	3790	269	2450
207 (vert.)	Oct. 25, 2017	BOR	2632	Oct. 25, 2017	BOR	1.9	53	37	55.8	3750	266	2300
261 (B1:10)	Oct. 25, 2017	BOR	3067	Oct. 25, 2017	BOR	2.2	47	37	49.5	3560	253	2200
262 (B1:10)	Oct. 25, 2017	BOR	3272	Oct. 25, 2017	BOR	2.6	47	37	49.5	3650	259	2550
227 (vert.)	Oct. 26, 2017	BOR	4389	Oct. 26, 2017	BOR	3.1	48	36	50.5	3730	265	3200
226 (vert.)	Oct. 26, 2017	BOR	4710	Oct. 26, 2017	BOR	3.7	46	37	48.4	3620	257	3400
224 (vert.)	Oct. 26, 2017	BOR	4888	Oct. 26, 2017	BOR	3.6	46	37	48.4	3670	261	3400
279 (B1:10)	Oct. 26, 2017	BOR	4273	Oct. 26, 2017	BOR	3.6	43	36	45.3	3500	248	3300

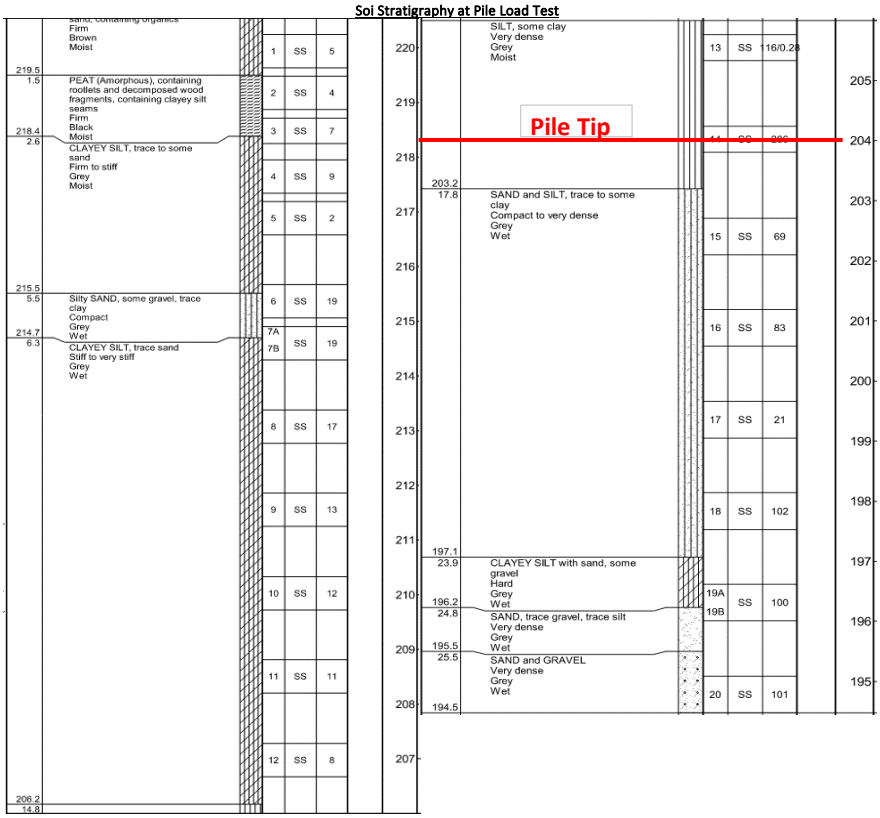
CAPWAP									Pile Design Capacity, FIDR (kN)	
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type	Factored ULS	SLS for 25 mm Settlement
No CAPWAP Data Available									1275*	1050

* 1700 kN ULS (not factored) was used for friction piles based on static load test from FIDR recommendation

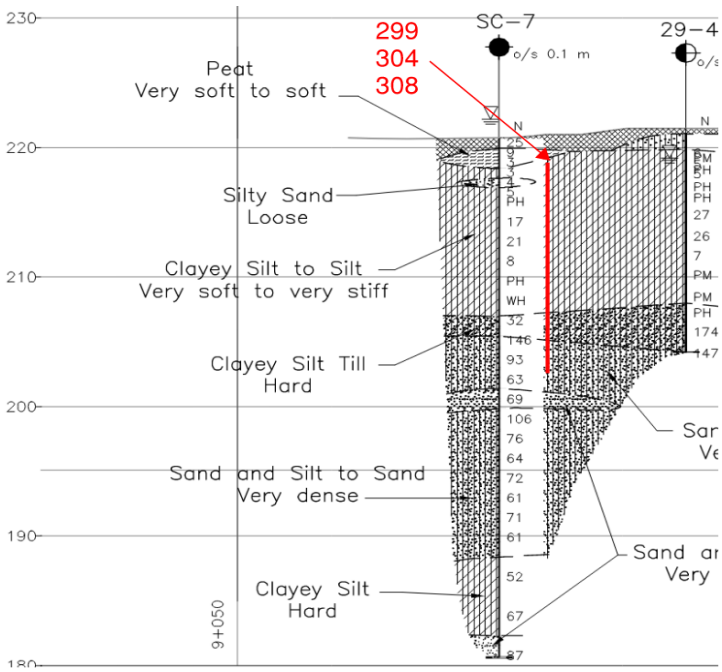
Pile Load Test - Load vs. Displacement

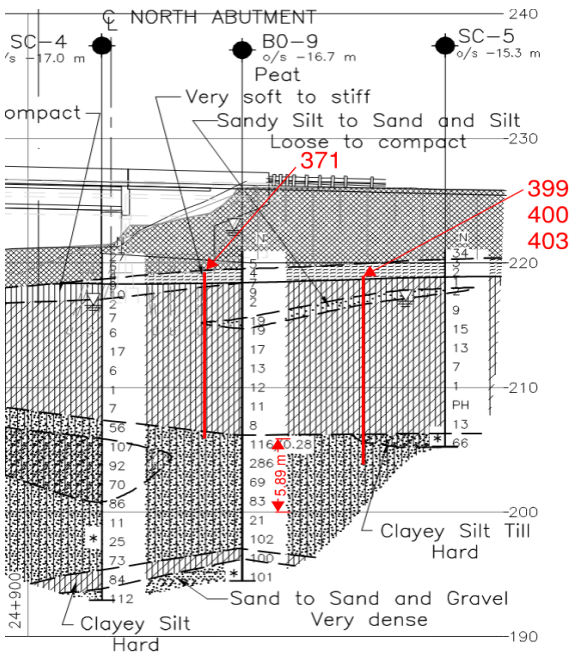


Soi Stratigraphy at Pile Load Test

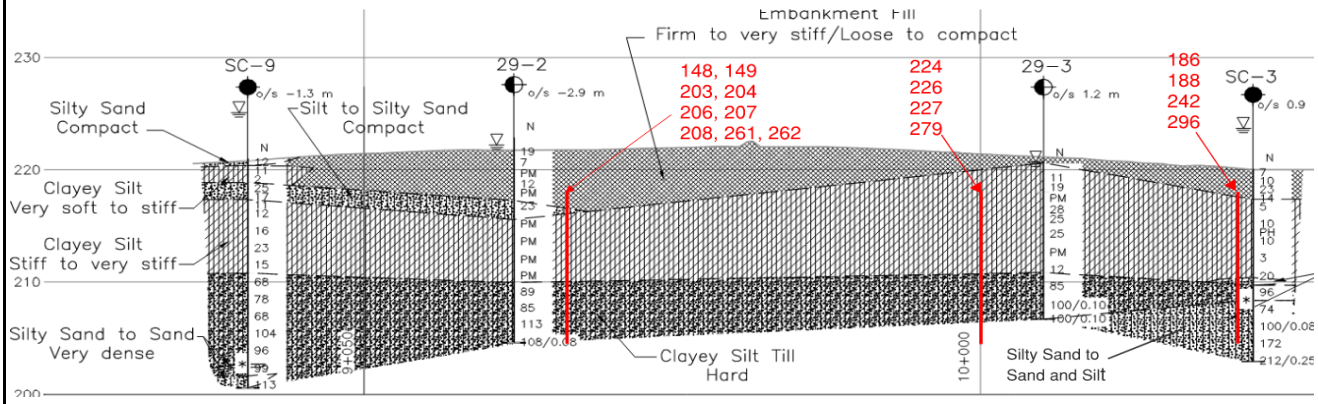


NORTH ABUTMENT

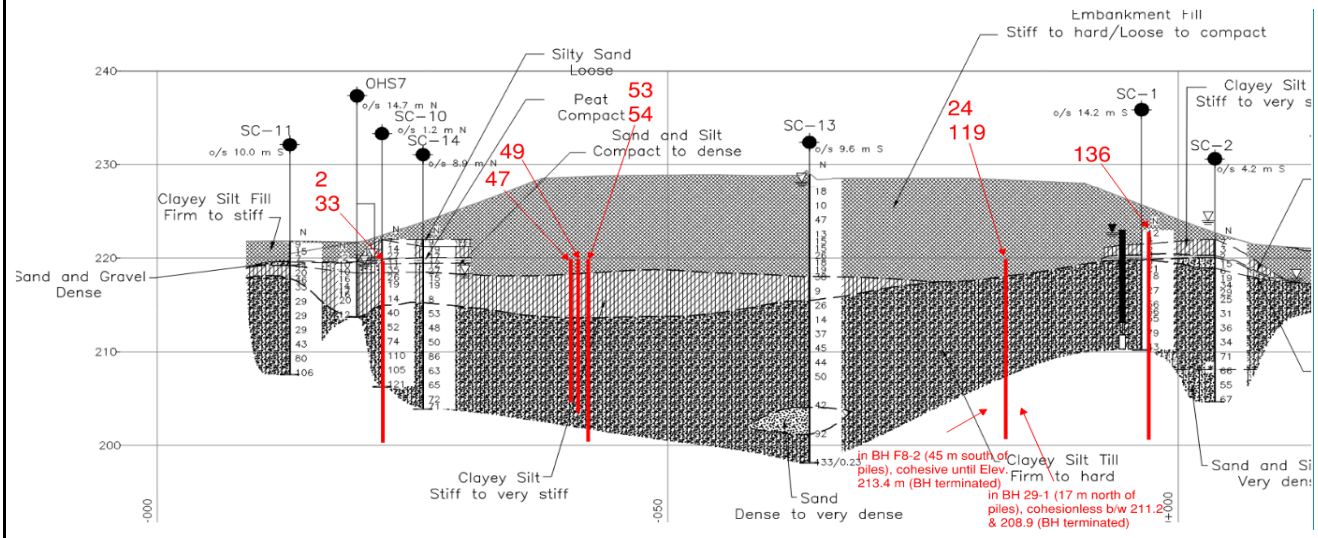




PIER



SOUTH ABUTMENT



Site No:	14	Project:	Hwy 427 over Rainbow Creek- NBL & SBL

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Thurber. Foundation Investigation and Design Report, Highway 427 Expansion - Package 1A (100% Submission), Hwy 427 NBL and SBL Bridges over Rainbow Creek (Bridges 11A/11B), May 15, 2019. Report No. H427-1A-FND-REP-001-F
Contract Dwgs	Structural Drawings Provided
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Rainbow Creek Bridge, North Abutment. Project Number BRM-00607283-A0 (Nov. 6, 2018)
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Rainbow Creek Bridge, North Abutment. Project Number BRM-00607283-A0 (Nov. 6, 2018)
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Rainbow Creek Bridge, South Abutment. Project Number BRM-00607283-A0 (Jan. 8, 2019)
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Rainbow Creek Bridge, South Abutment SBL. Project Number BRM-00607283-A0 (Jan. 30, 2019)
Pile Logs	P1A-B11A-034-B-001, P1A-034-B-003, P1A-B11B-034-A-002, P1A-B11B-034-A-004

Pile I.D.	Location	Soil Stratum	Pile Type
P63 (Vert.)	North Abutment-SBL	Cohesionless	End Bearing
P60 (Vert.)	North Abutment-SBL	Cohesionless	End Bearing
P60 (Vert.)	North Abutment-SBL	Cohesionless	End Bearing
P58 (Vert.)	North Abutment-SBL	Cohesionless	End Bearing
P56 (Vert.)	North Abutment-SBL	Cohesionless	End Bearing
P69 (Vert.)	North Abutment-SBL	Cohesionless	End Bearing
P79 (Vert.)	North Abutment-SBL	Cohesionless	End Bearing
P50 (Vert.)	North Abutment-NBL	Cohesionless	End Bearing
P33 (Vert.)	North Abutment-NBL	Cohesive	End Bearing
P29 (Vert.)	North Abutment-NBL	Cohesionless	End Bearing
P59 (Vert.)	North Abutment-NBL	Cohesive	End Bearing
P57 (Vert.)	North Abutment-NBL	Cohesive	End Bearing
P91 (Vert.)	South Abutment-SBL	Cohesive	End Bearing
P91 (Vert.)	South Abutment-SBL	Cohesive	End Bearing
P80 (Vert.)	South Abutment-SBL	Cohesive	End Bearing
P102 (Vert.)	South Abutment-SBL	Cohesive	End Bearing
P88 (Vert.)	South Abutment-SBL	Cohesive	End Bearing
P82 (Vert.)	South Abutment-SBL	Cohesive	End Bearing
P98 (Vert.)	South Abutment-SBL	Cohesive	End Bearing
P1 (Vert.)	South Abutment-NBL	Cohesionless	End Bearing
P14 (Vert.)	South Abutment-NBL	Cohesionless	End Bearing
P27 (Vert.)	South Abutment-NBL	Cohesive	End Bearing

Vert.	Vertical Pile
EOID	End of Initial Drive
EOD	End of Drive
BOR	Beginning of Restrike
EOR	End of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Location from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
P63 (Vert.)	North Abutment-SBL	HP360 x 174	12.24	-	8.5	20.9	Yes	-	175.7	167.2
P60 (Vert.)	North Abutment-SBL		12.49	-	8.5	21.3	Yes	-	175.8	167.3
P60 (Vert.)	North Abutment-SBL		12.49	-	9.5	21.3	Yes	-	175.8	166.3
P58 (Vert.)	North Abutment-SBL		12.23	-	9.5	20.9	Yes	-	175.7	166.2
P56 (Vert.)	North Abutment-SBL		12.49	-	9.2	21.3	Yes	-	175.9	166.7
P69 (Vert.)	North Abutment-SBL		12.47	-	8	21.3	Yes	-	175.8	167.8
P79 (Vert.)	North Abutment-SBL		12.46	-	9	21.3	Yes	-	175.2	166.2
P50 (Vert.)	North Abutment-NBL		12.41	-	7.6	21.2	Yes	-	174.8	167.2
P33 (Vert.)	North Abutment-NBL		12.42	-	8.1	21.2	Yes	-	175	166.9
P29 (Vert.)	North Abutment-NBL		12.22	-	7.5	20.9	Yes	-	175.1	167.6
P59 (Vert.)	North Abutment-NBL		12.58	-	9.5	21.5	Yes	-	175.7	166.2
P57 (Vert.)	North Abutment-NBL		12.23	-	9	20.9	Yes	-	175.7	166.7
P91 (Vert.)	South Abutment-SBL		15.35	-	10.3	26.2	Yes	-	177.7	167.4
P91 (Vert.)	South Abutment-SBL		15.35	-	10.35	26.2	Yes	-	177.7	167.35
P80 (Vert.)	South Abutment-SBL		15.52	-	9.9	26.5	Yes	-	177.1	167.2
P102 (Vert.)	South Abutment-SBL		15.5	-	8.2	26.5	Yes	-	176.5	168.3
P88 (Vert.)	South Abutment-SBL		15.48	-	9.4	26.4	Yes	-	177.8	168.4
P82 (Vert.)	South Abutment-SBL		15.52	-	9.25	26.5	Yes	-	177.2	167.95
P98 (Vert.)	South Abutment-SBL		15.5	-	9.4	26.5	Yes	-	177	167.6
P1 (Vert.)	South Abutment-NBL		15.52	-	8.3	26.5	Yes	-	176.8	168.5
P14 (Vert.)	South Abutment-NBL		15.36	-	8.35	26.2	Yes	-	176.6	168.25
P27 (Vert.)	South Abutment-NBL		15.36	-	8.9	26.2	Yes	-	175.7	166.8

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Final Pile Installation Date
P63 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110	Terex HC110-1 Crawler Crane	Fixed	Oct. 22, 2018
P60 (Vert.)					No				Oct. 19, 2018
P60 (Vert.)					No				Oct. 22, 2018
P58 (Vert.)					No				Oct. 22, 2018
P56 (Vert.)					No				Oct. 22, 2018
P69 (Vert.)					No				Oct. 22, 2018
P79 (Vert.)					No				Oct. 22, 2018
P50 (Vert.)					No				Oct. 30, 2018
P33 (Vert.)					No				Oct. 30, 2018
P29 (Vert.)					No				Oct. 30, 2018
P59 (Vert.)					No				Oct. 30, 2018
P57 (Vert.)					No				Oct. 30, 2018
P91 (Vert.)					No				Dec. 19, 2019
P91 (Vert.)					No				Dec. 19, 2019
P80 (Vert.)					No				Dec. 18, 2019
P102 (Vert.)					No				Dec. 18, 2019
P88 (Vert.)					No				Dec. 20, 2019
P82 (Vert.)					No				Dec. 19, 2019
P98 (Vert.)					No				Jan. 7, 2019
P1 (Vert.)					No				Dec. 18, 2019
P14 (Vert.)					No				Dec. 19, 2019
P27 (Vert.)					No				Dec. 18, 2019

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
P63 (Vert.)	Oct. 22, 2018	EOID	8790	Oct. 22, 2018	EOID	5.9	42.0	36	38.2	4970	224	2900
P60 (Vert.)	Oct. 19, 2018	BOR	6448	Oct. 22, 2018	BOR	3.6	50.0	35	45.5	5220	235	2200
P60 (Vert.)	Oct. 22, 2018	EOD	6449	Oct. 22, 2018	EOD	4.2	47.0	35	42.7	5130	231	2800
P58 (Vert.)	Oct. 22, 2018	EOD	6783	Oct. 22, 2018	EOD	5.4	43.0	36	39.1	5090	229	2900
P56 (Vert.)	Oct. 22, 2018	BOR	7232	Oct. 22, 2018	BOR	4.0	45.0	36	40.9	5180	233	2800
P69 (Vert.)	Oct. 22, 2018	EOID	9571	Oct. 22, 2018	EOID	9.0	44.0	35	40.0	5030	227	3200
P79 (Vert.)	Oct. 22, 2018	EOID	7170	Oct. 22, 2018	EOID	4.6	42.0	36	38.2	4840	223	2800
P50 (Vert.)	Oct. 30, 2018	BOR	8605	Oct. 30, 2018	BOR	4.0	41.0	35	37.3	5130	231	2850
P33 (Vert.)	Oct. 30, 2018	BOR	8439	Oct. 30, 2018	BOR	3.7	39.0	35	35.5	5000	225	2800
P29 (Vert.)	Oct. 30, 2018	BOR	8269	Oct. 30, 2018	BOR	4.3	37.0	35	33.6	5020	226	3000
P59 (Vert.)	Oct. 30, 2018	EOR	7420	Oct. 30, 2018	EOR	4.3	40.0	36	36.4	4880	223	2900
P57 (Vert.)	Oct. 30, 2018	EOR	7397	Oct. 30, 2018	EOR	4.3	40.0	36	36.4	5020	233	2900
P91 (Vert.)	Dec. 19, 2019	DD	5854	Dec. 19, 2019	DD	3.9	40.0	39	36.4	4720	213	2500
P91 (Vert.)	Dec. 19, 2020	EOID	5883	Dec. 19, 2019	EOID	3.7	45.0	38	40.9	5000	225	2400
P80 (Vert.)	Dec. 19, 2021	BOR	9057	Dec. 19, 2019	BOR	4.2	42.0	39	38.2	4990	225	2900
P102 (Vert.)	Dec. 19, 2022	BOR	8126	Dec. 19, 2019	BOR	6.6	42.0	37	38.2	5170	240	3500
P88 (Vert.)	Jan. 23, 2020	BOR	6057	Jan. 23, 2019	BOR	3.1	50.0	36	45.5	5280	238	3000
P82 (Vert.)	Jan. 23, 2020	BOR	5998	Jan. 23, 2019	BOR	3.8	49.0	36	44.5	5540	250	3000
P98 (Vert.)	Jan. 23, 2020	BOR	5354	Jan. 23, 2019	BOR	2.9	44.0	36	40.0	4920	222	2900
P1 (Vert.)	Dec. 18, 2019	BOR	7762	Dec. 19, 2019	BOR	5.4	38.0	37	34.5	4670	211	2900
P14 (Vert.)	Dec. 19, 2019	EOID	6993	Dec. 19, 2019	EOID	6.5	44.0	37	40.0	4960	229	3100
P27 (Vert.)	Dec. 18, 2019	BOR	6595	Dec. 19, 2019	BOR	3.3	40.0	38	36.4	4830	218	2200

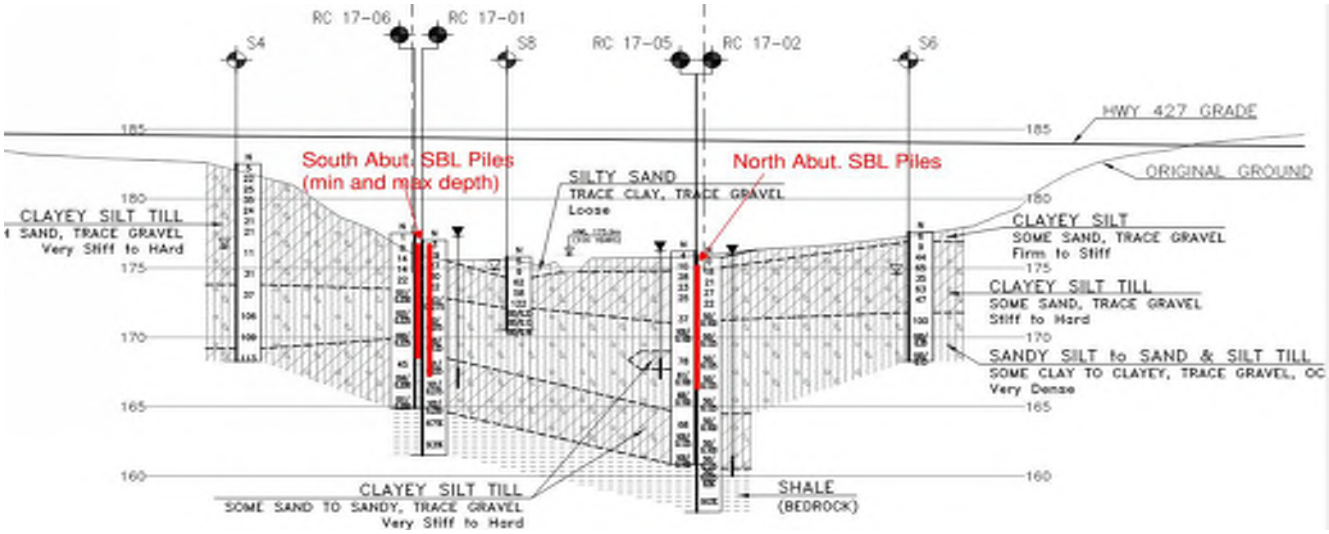
CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
P63 (Vert.)	-	-	-	-	-	-	-	-
P60 (Vert.)	-	-	-	-	-	-	-	-
P60 (Vert.)	-	-	-	-	-	-	-	-
P58 (Vert.)	-	-	-	-	-	-	-	-
P56 (Vert.)	BOR	4/25	1200	43	1600	57	2800	End Bearing
P69 (Vert.)	-	-	-	-	-	-	-	-
P79 (Vert.)	-	-	-	-	-	-	-	-
P50 (Vert.)	-	-	-	-	-	-	-	-
P33 (Vert.)	-	-	-	-	-	-	-	-
P29 (Vert.)	-	-	-	-	-	-	-	-
P59 (Vert.)	-	-	-	-	-	-	-	-
P57 (Vert.)	-	-	-	-	-	-	-	-
P91 (Vert.)	-	-	-	-	-	-	-	-
P91 (Vert.)	-	-	-	-	-	-	-	-
P80 (Vert.)	BOR	5/30	1200	41	1700	59	2900	End Bearing
P102 (Vert.)	-	-	-	-	-	-	-	-
P88 (Vert.)	-	-	-	-	-	-	-	-
P82 (Vert.)	-	-	-	-	-	-	-	-
P98 (Vert.)	BOR	6/52	750	26	2150	74	2900	End Bearing
P1 (Vert.)	BOR	5/23	1100	38	1800	62	2900	End Bearing
P14 (Vert.)	-	-	-	-	-	-	-	-
P27 (Vert.)	-	-	-	-	-	-	-	-

Axial Geotechnical Resistances for HP360 x 174 from FIDR

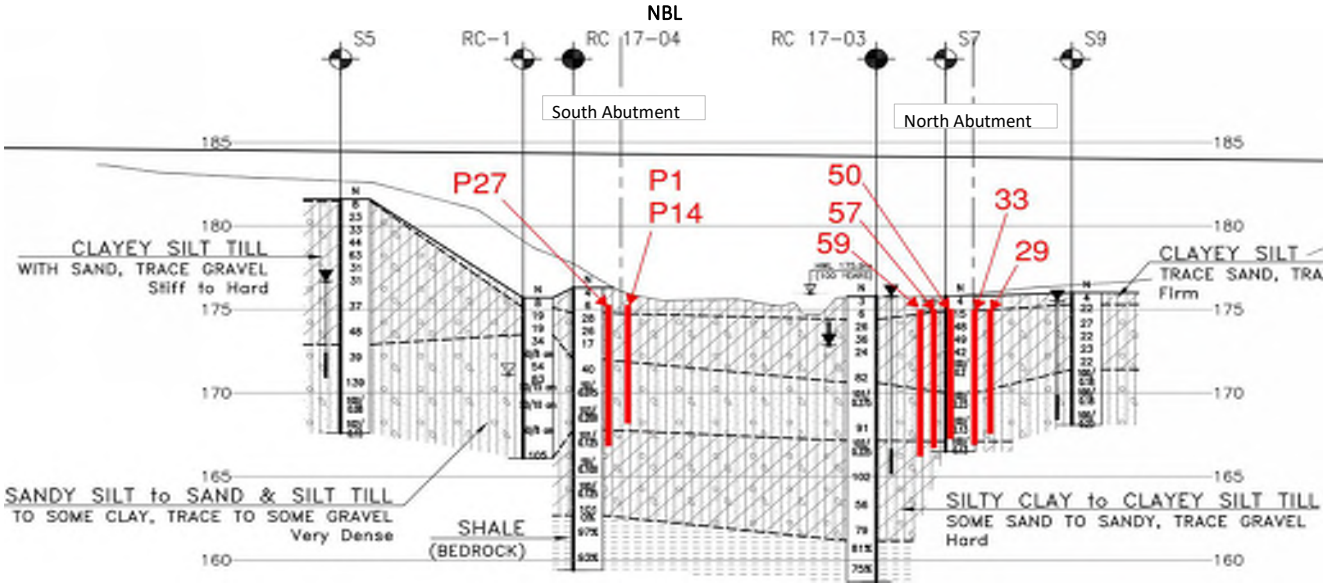
Location	Pile Tip. Elev. (m)	Founding Stratum	Factored ULS (kN)	Factored SLS (kN)
South Abutment (SBL)	167.0	Hard clayey silt till	1400	1100
	164.6	Shale	3000	3000
North Abutment (SBL)	167.0	V. Dense Sand and Silt Till	1400	1100
	160.6	Shale	3000	3000
South Abutment (NBL)	167.0	Hard clayey silt till	1400	1100
	162.7	Shale	3000	3000
North Abutment (NBL)	167.0	Hard clayey silt till	1400	1100
	161.1	Shale	3000	3000

Soil Stratigraphy at Pile Locations

SBL



NBL



Site No:	15	Project:	Langstaff Road Underpass - Highway 427 Expansion

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Thurber. Foundation Investigation and Design Report (100% Submission), Highway 427 Expansion, Langstaff Road Underpass (Structure B13), October 11, 2018. Report No. H427-4-FND-REP-003-E
Contract Dwgs	Structural Drawings Provided
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Langstaff Road Underpass. Project Number BRM-00607283-A0 (Oct. 19, 2018)
Pile Logs	H427-QMS-ITP-034-A Driven H-Piles, B13 - Langstaff Rd Underpass, East & West Abutment H-Piles

Pile I.D.	Location	Soil Stratum	Pile Type
P27 (Vert.)	West Abutment	Shale Bedrock	End Bearing
P32 (Vert.)	West Abutment	Shale Bedrock	End Bearing
P37 (Vert.)	West Abutment	Shale Bedrock	End Bearing
P20 (Vert.)	East Abutment	Shale Bedrock	End Bearing
P21 (Vert.)	East Abutment	Shale Bedrock	End Bearing
P23 (Vert.)	West Abutment	Shale Bedrock	End Bearing
P30 (Vert.)	West Abutment	Shale Bedrock	End Bearing
P42 (Vert.)	West Abutment	Shale Bedrock	End Bearing
P3 (Vert.)	East Abutment	Shale Bedrock	End Bearing
P16 (Vert.)	East Abutment	Shale Bedrock	End Bearing

EOID End of Initial Drive
BOR Beginning of Restrike
Vert. Vertical Pile

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
P27 (Vert.)	West Abutment	HP360 x 174	27.53	-	20	47.0	Yes	18.34	185.2	165.2
P32 (Vert.)	West Abutment		24.44	-	19.9	41.7	Yes	15.25	185.2	165.3
P37 (Vert.)	West Abutment		24.48	-	20.5	41.8	Yes	15.27	183.6	163.1
P20 (Vert.)	East Abutment		24.16	-	21.4	41.2	Yes	18.34*	185.5	164.1
P21 (Vert.)	East Abutment		24.53	-	21.3	41.9	Yes	18.34	184.46	163.16
P23 (Vert.)	West Abutment		24.43	-	19.95	41.7	Yes	6.09, 9.2	185.25	165.3
P30 (Vert.)	West Abutment		27.63	-	19.55	47.2	Yes	15.29	185.25	165.7
P42 (Vert.)	West Abutment		36	-	19.75	61.4	Yes	15.28	183.65	163.9
P3 (Vert.)	East Abutment		24.53	-	21.05	41.9	Yes	9.25	185.35	164.3
P16 (Vert.)	East Abutment		24.56	-	21.35	41.9	Yes	9.24	185.45	164.1

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
P27 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110	Terex HC110-1 Crawler Crane	Fixed	Sep. 24, 2018
P32 (Vert.)					No				Sep. 21, 2018
P37 (Vert.)					No				Oct. 2, 2018
P20 (Vert.)					No				Oct. 2, 2018
P21 (Vert.)					No				Oct. 2, 2018
P23 (Vert.)					No				Oct. 12, 2018
P30 (Vert.)					No				Oct. 11, 2018
P42 (Vert.)					No				Oct. 12, 2018
P3 (Vert.)					No				Oct. 9, 2018
P16 (Vert.)					No				Oct. 3, 2018

*Note: Not written in pile logs, assumsed based on adjacent pile in same pile group.

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
P27 (Vert.)	Oct. 2, 2018	BOR	6241	Oct. 2, 2018	BOR	4.0	46.0	35	41.8	5250	237	1900
P32 (Vert.)	Oct. 2, 2018	BOR	6231	Oct. 2, 2018	BOR	3.0	44.0	36	40.0	5020	226	1200
P37 (Vert.)	Oct. 2, 2018	BOR	4801	Oct. 2, 2018	BOR	3.0	43.0	36	39.1	4850	219	1100
P20 (Vert.)	Oct. 2, 2018	BOR	7824	Oct. 2, 2018	BOR	23.0	48.0	35	43.6	5150	239	4100
P21 (Vert.)	Oct. 2, 2018	EOID	7767	Oct. 2, 2018	EOID	31.0	50.0	34	45.5	5110	230	4100
P23 (Vert.)	Oct. 12, 2018	EOID	8278	Oct. 15, 2018	BOR	13.0	44.0	36	40.0	4940	223	3800
P30 (Vert.)	Oct. 11, 2018	EOID	8098	Oct. 15, 2018	BOR	13.0	42.0	36	38.2	4820	217	3800
P42 (Vert.)	Oct. 12, 2018	BOR	7830	Oct. 15, 2018	BOR	12.0	42.0	36	38.2	4720	213	3750
P3 (Vert.)	Oct. 9, 2018	BOR	7736	Oct. 15, 2018	BOR	50.0	47.0	35	42.7	5020	226	4100
P16 (Vert.)	Oct. 9, 2018	BOR	7079	Oct. 15, 2018	BOR	23.0	48.0	35	43.6	5190	234	4200

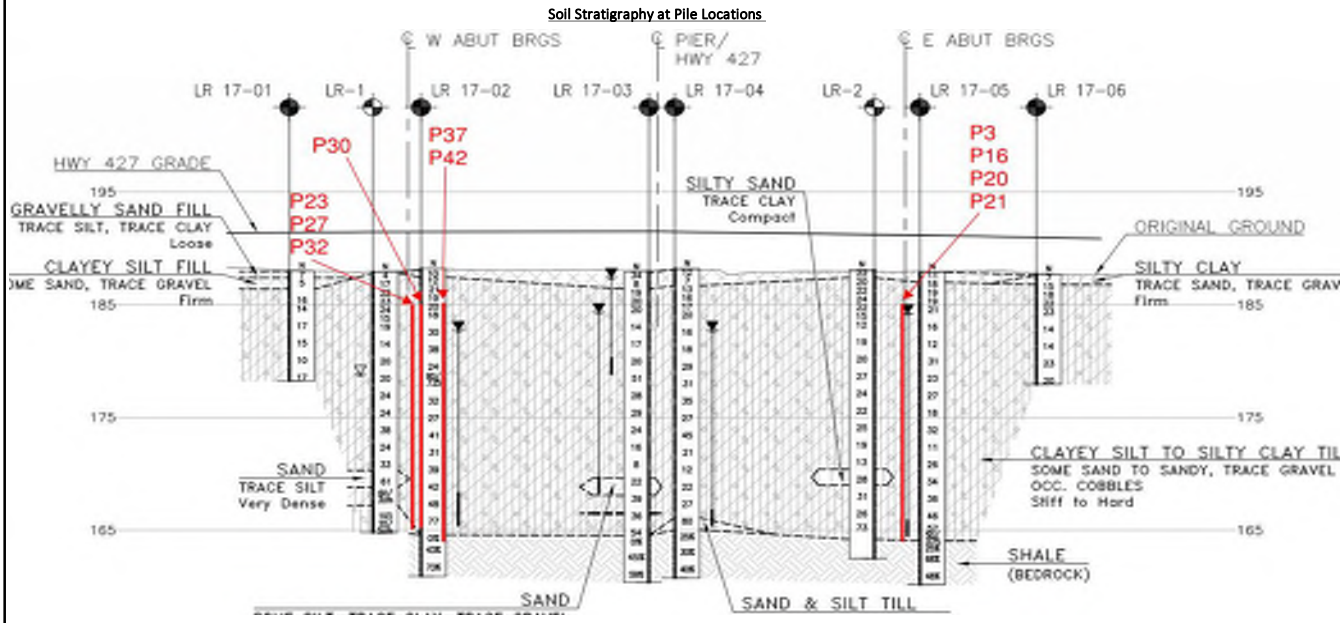
CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
P27 (Vert.)	-	-	-	-	-	-	-	-
P32 (Vert.)	-	-	-	-	-	-	-	-
P37 (Vert.)	-	-	-	-	-	-	-	-
P20 (Vert.)	-	-	-	-	-	-	-	-
P21 (Vert.)	EOID	10/8	1150	28	2950	72	4100	End Bearing
P23 (Vert.)	BOR	10/19	1200	32	2600	68	3800	End Bearing
P30 (Vert.)	-	-	-	-	-	-	-	-
P42 (Vert.)	-	-	-	-	-	-	-	-
P3 (Vert.)	-	-	-	-	-	-	-	-
P16 (Vert.)	-	-	-	-	-	-	-	-

Axial Geotechnical Resistances for HP360 x 174 from FIDR

Location	Approx. Pile Tip Elev. (m)	Founding Stratum	Factored ULS (kN)*	Factored SLS (kN)
West Abutment	175.0 or below	Very Stiff to Hard Till	1400	1100
	164.6	Hard Till or Shale	2800	2400
Center Pier	164.5 to 165	Hard Till or Shale	2800	2400
East Abutment	175.0 or below	Very Stiff to Hard Till	1400	1100
	164.0 to 164.2	Hard Till or Shale	2800	2400

*** As per PDA report, target ULS was 3640 during PDA testing**

Soil Stratigraphy at Pile Locations

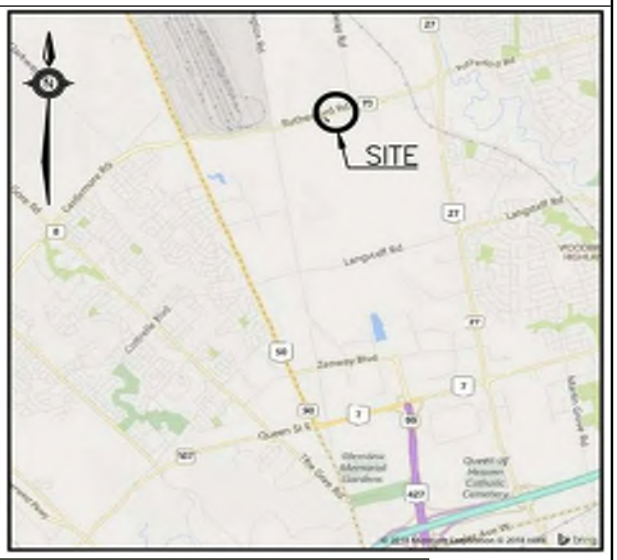


Site No:	16	Project:	Hwy 427 over Rutherford Rd.-NBL & SBL

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Thurber. Foundation Investigation and Design Report, Highway 427 Expansion - Package 7 (100% Submission), Rutherford Road Overpass NBL and SBL (Bridges 15A/15B), November 12, 2019. Report No. H427-7-FND-REP-001-E
Contract Dwgs	Structural Drawings Provided
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Rutherford Road Underpass. Project Number BRM-00607283-A0 (Aug. 8, 2019)
Pile Logs	P7-B15B-034-D-002

Pile I.D.	Location	Soil Stratum	Pile Type
P97 (Vert.)	North Abut. SBL	Cohesive/Cohesionless	Friction/End Bearing
P90 (Vert.)	North Abut. SBL	Cohesive/Cohesionless	Friction/End Bearing
P73 (Vert.)	North Abut. SBL	Cohesive/Cohesionless	Friction/End Bearing
P44 (Vert.)	North Abut. NBL	Cohesive	Friction/End Bearing
P36 (Vert.)	North Abut. NBL	Cohesive	Friction/End Bearing
P25 (Vert.)	North Abut. NBL	Cohesive	Friction/End Bearing



Vert. Vertical Pile
BOR Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
P97 (Vert.)	North Abut. SBL	HP360 x 174	24.42	-	15.5	41.7	Yes	9.16	194.9	179.4
P90 (Vert.)	North Abut. SBL		24.46	-	14.75	41.8	Yes	12.23	194.95	180.2
P73 (Vert.)	North Abut. SBL		24.49	-	16.25	41.8	Yes	9.16	194.45	178.2
P44 (Vert.)	North Abut. NBL		24.5	-	15.75	41.8	Yes	9.17	194.25	178.5
P36 (Vert.)	North Abut. NBL		24.5	-	15.75	41.8	Yes	9.17	194.25	178.5
P25 (Vert.)	North Abut. NBL		24.5	-	15.4	41.8	Yes	9.18	194.2	178.8

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
P97 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110	Terex HC110-1 Crawler Crane	Fixed	Jul. 27, 2019
P90 (Vert.)					No				Jul. 29, 2019
P73 (Vert.)					No				Jul. 27, 2019
P44 (Vert.)					No				Jul. 29, 2019
P36 (Vert.)					No				Jul. 29, 2019
P25 (Vert.)					No				Jul. 29, 2019

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
P97 (Vert.)	Jul. 30, 2019	BOR	6754	Jul. 30, 2019	BOR	10.9	42.0	37	38.2	4540	204	3100
P90 (Vert.)	Jul. 30, 2019	BOR	6287	Jul. 30, 2019	BOR	9.3	41.0	38	37.3	4400	198	2900
P73 (Vert.)	Jul. 30, 2019	BOR	6510	Jul. 30, 2019	BOR	8.6	39.0	38	35.5	4340	195	2800
P44 (Vert.)	Jul. 30, 2019	BOR	5713	Jul. 30, 2019	BOR	4.5	37.0	39	33.6	4320	195	2300
P36 (Vert.)	Jul. 30, 2019	BOR	5416	Jul. 30, 2019	BOR	4.6	37.0	39	33.6	4290	193	2300
P25 (Vert.)	Jul. 30, 2019	BOR	6358	Jul. 30, 2019	BOR	6.1	38.0	39	34.5	4460	201	2600

CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
P97 (Vert.)	-	-	-	-	-	-	-	-
P90 (Vert.)	-	-	-	-	-	-	-	-
P73 (Vert.)	BOR	10/29	1675	60	1125	40	2800	Friction
P44 (Vert.)	-	-	-	-	-	-	-	-
P36 (Vert.)	BOR	10/54	1200	52	1100	48	2300	Friction
P25 (Vert.)	-	-	-	-	-	-	-	-

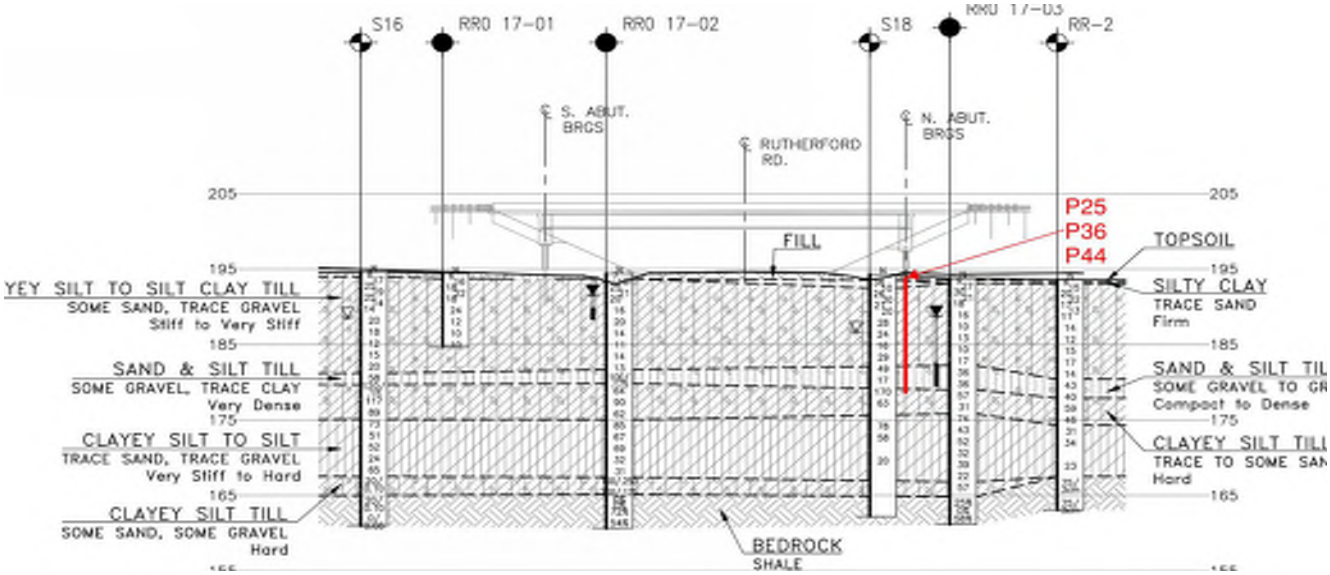
Axial Geotechnical Resistances for HP360 x 174 from FIDR

Location	Pile Tip. Elev. (m)	Founding Stratum	Factored ULS (kN)*	Factored SLS (kN)
North Abutment (NBL)	178.0	Hard clayey silt till	1000	800
	164.8	Shale	2400	2400
South Abutment (NBL)	178.0	V. Dense Sand and Silt Till	1200	1000
	165.1	Shale	2400	2400
North Abutment (SBL)	178.0	Hard clayey silt till	1200	1000
	163.9	Shale	2400	2400
South Abutment (SBL)	178.0	Hard clayey silt till	1200	1000
	166.2	Shale	2400	2400

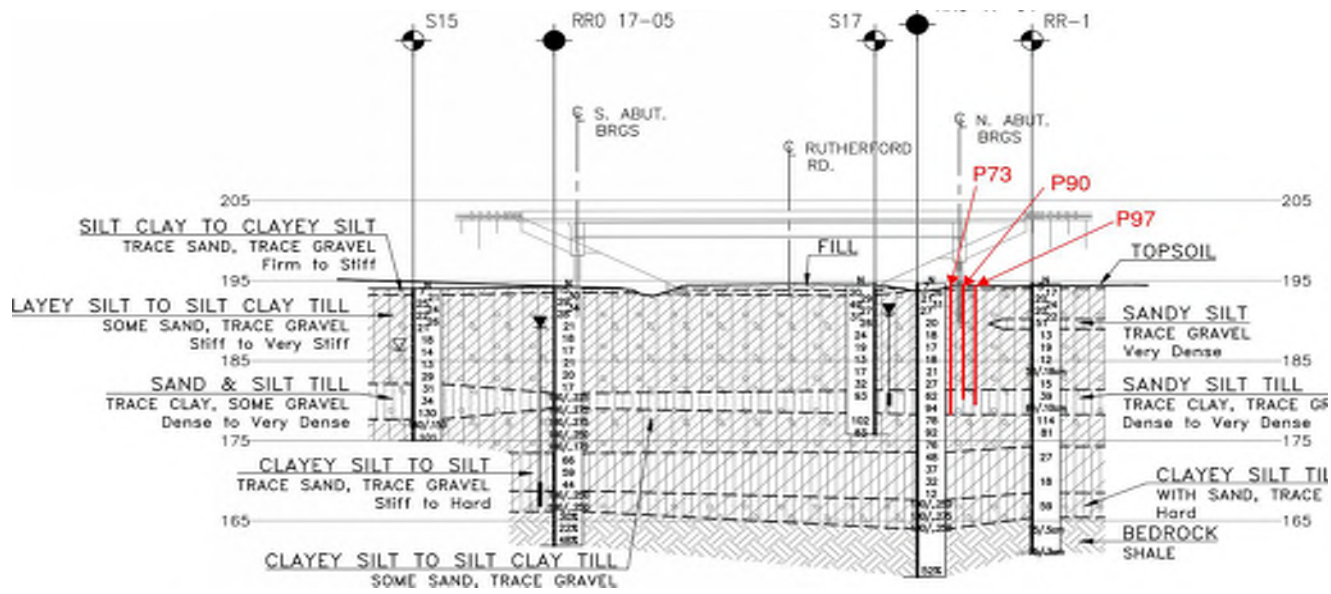
* Target factored ULS of 1050 kN for SBL and 1000 kN for NBL as per PDA memos.

Soil Stratigraphy at Pile Locations

NBL



SBL



Site No:	17	Project:	Hwy 427 over West Robinson Creek-NBL & SBL

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Thurber. Foundation Investigation and Design Report, Highway 427 Expansion - Package 3A (100% Submission), Hwy 427 NBL/SBL Bridges over West Robinson Creek Bridges (Bridges 16A/16B), August 27, 2019. Report No. H427-3A-FND-REP-003-F
Contract Dwgs	Structural Drawings Provided
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Over West Robinson Creek , South Abutment, April 12 , 2019 Visit. Project Number BRM-00607283-A0 (Apr. 22, 2019)
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Over West Robinson Creek , North Abutment, April 30 and May 6, 2019 Visits. Project Number BRM-00607283-A0 (May 24, 2019)
Pile Logs	P3A-B16A-034-B-001, P3A-B16A-034-B-002, P3A-B16A-034-B-003, P3A-B16A-034-B-004

Pile I.D.	Location	Soil Stratum	Pile Type
P22 (Vert.)	North Abut. NBL	Cohesive	End Bearing
P41 (Vert.)	North Abut. NBL	Cohesive	End Bearing
P71 (Vert.)	North Abut. SBL	Cohesive	End Bearing
P71 (Vert.)	North Abut. SBL	Cohesive	End Bearing
P62 (Vert.)	North Abut. SBL	Cohesive	End Bearing
P71 (Vert.)	North Abut. SBL	Cohesive	End Bearing
P68 (Vert.)	North Abut. SBL	Cohesive	End Bearing
P61 (Vert.)	North Abut. SBL	Cohesive	End Bearing
P5 (Vert.)	South Abut. NBL	Cohesive	End Bearing
P13 (Vert.)	South Abut. NBL	Cohesive	End Bearing
P42 (Vert.)	South Abut. SBL	Cohesive	End Bearing
P57 (Vert.)	South Abut. SBL	Cohesive	End Bearing

Vert. Vertical Pile
BOR Beginning of Restrike
EOR End of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe /Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
P22 (Vert.)	North Abut. NBL	HP310 x 110	15.29	-	6.5	26.1	Yes	-	193.1	186.6
P41 (Vert.)	North Abut. NBL		15.29	-	6.5	26.1	Yes	-	193.4	186.9
P71 (Vert.)	North Abut. SBL		13.85	-	11.9	23.6	Yes	-	193.5	181.6
P71 (Vert.)	North Abut. SBL		13.85	-	12	23.6	Yes	-	193.5	181.5
P62 (Vert.)	North Abut. SBL		13.85	-	11.2	23.6	Yes	-	193.5	185.5
P71 (Vert.)	North Abut. SBL		13.85	-	11.6	23.6	Yes	-	193.5	181.9
P68 (Vert.)	North Abut. SBL		13.85	-	8	23.6	Yes	-	193.5	185.5
P61 (Vert.)	North Abut. SBL		13.85	-	7.25	23.6	Yes	-	193.75	186.5
P5 (Vert.)	South Abut. NBL		13.77	-	9	23.5	Yes	-	196.3	187.3
P13 (Vert.)	South Abut. NBL		13.77	-	8.8	23.5	Yes	-	196.2	187.4
P42 (Vert.)	South Abut. SBL		12.23	-	10	20.9	Yes	-	196.2	186.2
P57 (Vert.)	South Abut. SBL		12.23	-	9	20.9	Yes	-	196.1	187.1

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
P22 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110	Terex HC110-1 Crawler Crane	Fixed	Apr. 29, 2019
P41 (Vert.)					No				Apr. 29, 2019
P71 (Vert.)					No				Apr. 25, 2019
P71 (Vert.)					No				Apr. 25, 2019
P62 (Vert.)					No				May 2, 2019
P71 (Vert.)					No				May 2, 2019
P68 (Vert.)					No				May 2, 2019
P61 (Vert.)					No				Apr. 29, 2019
P5 (Vert.)					No				Apr. 10, 2019
P13 (Vert.)					No				Apr. 11, 2019
P42 (Vert.)					No				Apr. 3, 2019
P57 (Vert.)					No				Apr. 10, 2019

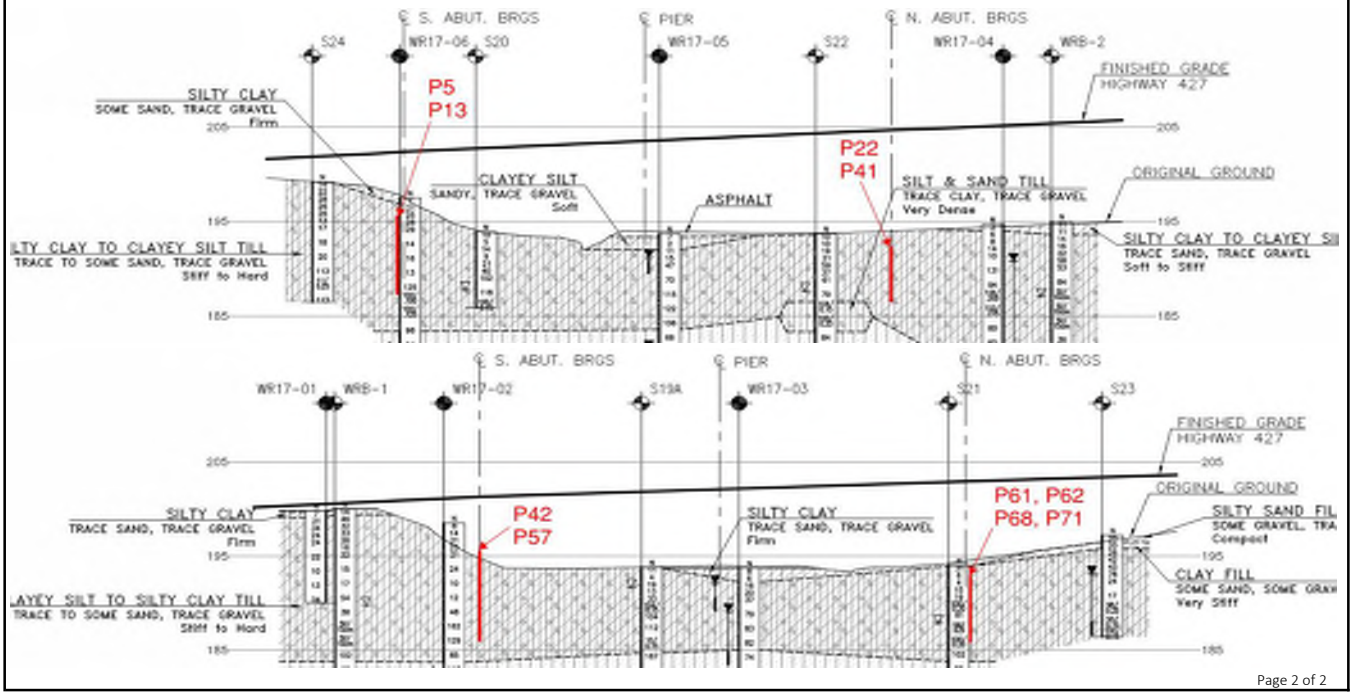
Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
P22 (Vert.)	Apr. 30, 2019	BOR	6926	Apr. 30, 2019	BOR	4.0	42.0	36	38.2	3560	252	2800
P41 (Vert.)	Apr. 30, 2019	BOR	6359	Apr. 30, 2019	BOR	3.8	38.0	37	34.5	3390	241	2600
P71 (Vert.)	Apr. 30, 2019	BOR	4776	Apr. 30, 2019	BOR	2.1	43.0	38	39.1	3260	232	1800
P71 (Vert.)	Apr. 30, 2019	EOR	4677	Apr. 30, 2019	EOR	2.1	38.0	38	34.5	3240	230	1800
P62 (Vert.)	Apr. 30, 2019	BOR	4742	Apr. 30, 2019	BOR	2.2	41.0	38	37.3	3110	221	1900
P71 (Vert.)	May 6, 2019	BOR	4988	May 6, 2019	BOR	2.2	45.0	37	40.9	3510	249	2000
P68 (Vert.)	May 6, 2019	BOR	4289	May 6, 2019	BOR	2.0	40.0	38	36.4	3380	240	1800
P61 (Vert.)	May 6, 2019	BOR	5743	May 6, 2019	BOR	2.3	39.0	39	35.5	3220	224	2000
P5 (Vert.)	Apr. 12, 2019	BOR	5266	Apr. 12, 2019	BOR	3.6	48.0	37.0	43.6	3670	260	2800
P13 (Vert.)	Apr. 12, 2019	BOR	7531	Apr. 12, 2019	BOR	4.5	37.0	39.0	33.6	3060	217	2500
P42 (Vert.)	Apr. 12, 2019	BOR	8471	Apr. 12, 2019	BOR	10.0	41.0	38.0	37.3	3660	260	3550
P57 (Vert.)	Apr. 12, 2019	BOR	7096	Apr. 12, 2019	BOR	6.5	43.0	38.0	39.1	3370	239	2675

CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
P22 (Vert.)	-	-	-	-	-	-	-	-
P41 (Vert.)	BOR	3.8/25	500	19	2100	81	2600	End Bearing
P71 (Vert.)	-	-	-	-	-	-	-	-
P71 (Vert.)	-	-	-	-	-	-	-	-
P62 (Vert.)	-	-	-	-	-	-	-	-
P71 (Vert.)	BOR	2.2/25	575	29	1425	71	2000	End Bearing
P68 (Vert.)	-	-	-	-	-	-	-	-
P61 (Vert.)	-	-	-	-	-	-	-	-
P5 (Vert.)	-	-	-	-	-	-	-	-
P13 (Vert.)	BOR	10/56	825	33	1675	67	2500	End Bearing
P42 (Vert.)	-	-	-	-	-	-	-	-
P57 (Vert.)	BOR	8/31	900	34	1775	66	2675	End Bearing

Axial Geotechnical Resistances for HP310 x 110 from FIDR

Location	Pile Tip. Elev. (m)	Founding Stratum	Factored ULS (kN)*	Factored SLS (kN)
South Abutment (SBL)	186.0	Hard cohesive till	1000	800
Pier (SBL)	165 or lower	V. Dense silt and sand till	1600	1400
North Abutment (SBL)	186.0	Hard cohesive till	1000	800
South Abutment (NBL)	186.0	Hard cohesive till	1000	800
Pier (NBL)	185.0	Hard clayey silt till	1000	800
North Abutment (NBL)	185.5	Hard cohesive till	1000	800

Soil Stratigraphy at Pile Locations



Site No:	18	Project:	Hwy 427 - CPR at McGillivray Rd-NBL & SBL

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Thurber. Foundation Investigation and Design Report (100% Submission), Highway 427 Expansion, Hwy 427 NBL/SBL CPR/McGillivray Overheads (Structures B17A/B17B), Oct. 11, 2018. Report No. H427-3A-FND-REP-004-D
Contract Dwgs	Structural Drawings Provided
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Hwy. 427 at CPR/McGillivray Road Overhead, November 22 , 2018 Visit. Project Number BRM-00607283-A0 (Dec. 14, 2019)
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Hwy. 427 at CPR/McGillivray Road Overhead, South Abutment, February 13, 2019 Visit. Project Number BRM-00607283-A0 (Mar. 12, 2019)
Pile Logs	P5-B17A-034-B-001, P5-B17A-034-A-002, P5-B17A-034-B-003, P5-B17A-S.Abut-034-A-004, P5-B17B-034-A-005, P5-B17A-034-A-006, P5-B17A-034-A-008, P5-B17B-034-A-007,

Pile I.D.	Location	Soil Stratum	Pile Type
P74 (B1:8)	North Pier: NBL	Cohesionless	End Bearing
P65 (B1:8)	North Pier: NBL	Cohesionless	End Bearing
P91 (Vert.)	North Pier: SBL	Cohesionless	End Bearing
P126 (Vert.)	South Abut.: SBL	Layered/Cohesionless	Friction/End Bearing
P120 (Vert.)	South Abut.: SBL	Layered/Cohesionless	Friction/End Bearing
P4 (Vert.)	South Abut.: NBL	Cohesionless	End Bearing
P6 (Vert.)	South Abut.: NBL	Cohesionless	End Bearing

Vert. Vertical Pile
B1:8 Battered at 8 Vertical to 1 Horizontal
BOR Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
P74 (B1:8)	North Pier: NBL	HP310 x 110	16.85	-	14.5	28.8	Yes	-	201.9	187.4
P65 (B1:8)	North Pier: NBL		16.86	-	13.9	28.8	Yes	-	201.8	187.9
P91 (Vert.)	North Pier: SBL	HP360 x 174	26.4	-	14	45.1	Yes	18.38	202.4	188.4
P126 (Vert.)	South Abut.: SBL		21.48	-	12.6	36.7	Yes	9.26	200.9	188.3
P120 (Vert.)	South Abut.: SBL		21.48	-	12.8	36.7	Yes	9.25	200.9	188.1
P4 (Vert.)	South Abut.: NBL		24.48	-	13	41.8	Yes	9.16	200.4	187.4
P6 (Vert.)	South Abut.: NBL		24.49	-	12	41.8	Yes	9.17	200.5	188.5

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
P74 (B1:8)	Berminghammer B-32	Diesel Hammer	3200	840	No	110	Terex HC110-1 Crawler Crane	Fixed	Nov. 21, 2018
P65 (B1:8)					No				Nov. 21, 2018
P91 (Vert.)					No				Nov. 20, 2018
P126 (Vert.)					No				Feb. 7, 2019
P120 (Vert.)					No				Feb. 7, 2019
P4 (Vert.)					No				Feb. 8, 2019
P6 (Vert.)					No				Feb. 8, 2019

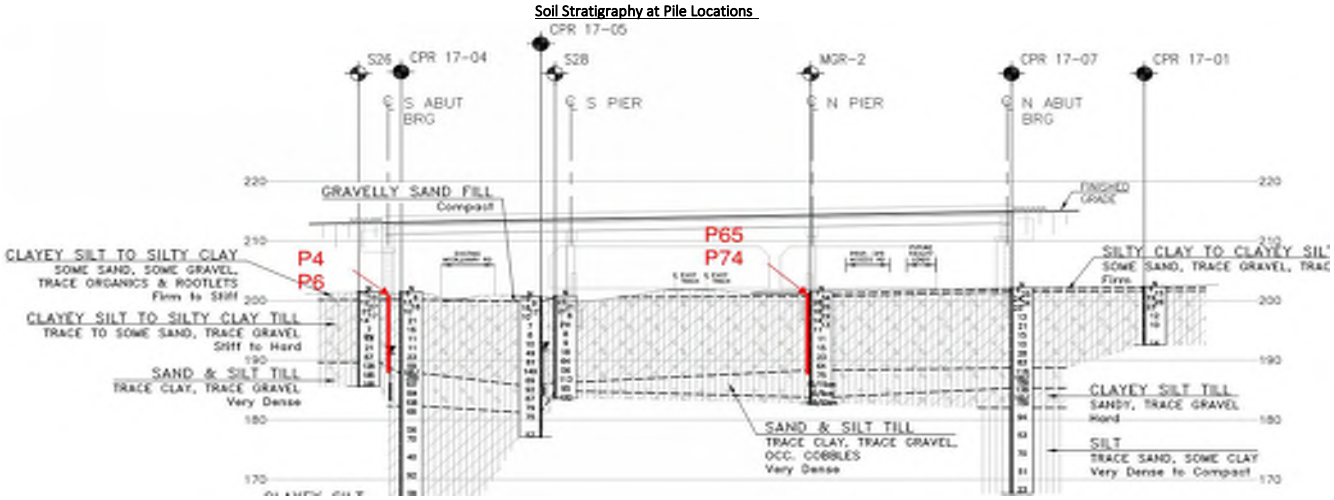
Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
P74 (B1:8)	Nov. 22, 2018	BOR	8447	Nov. 22, 2018	BOR	8.7	36.0	35	32.7	3250	231	3200
P65 (B1:8)	Nov. 22, 2018	BOR	7657	Nov. 22, 2018	BOR	7.6	31.0	36	28.2	3040	216	2800
P91 (Vert.)	Nov. 22, 2018	BOR	7684	Nov. 22, 2018	BOR	6.8	43.0	34	39.1	5040	227	3300
P126 (Vert.)	Feb. 13, 2019	BOR	6866	Feb. 13, 2019	BOR	5.4	51.0	35	46.4	5190	234	2800
P120 (Vert.)	Feb. 13, 2019	BOR	7012	Feb. 13, 2019	BOR	6.3	55.0	35	50.0	5530	249	3300
P4 (Vert.)	Feb. 13, 2019	BOR	6206	Feb. 13, 2019	BOR	5.6	42.0	37	38.2	4700	212	2850
P6 (Vert.)	Feb. 13, 2019	BOR	6911	Feb. 13, 2019	BOR	7.1	47.0	37	42.7	4940	223	3200

CAPWAP								
Pile No.	Event	Equivalent Pres. blows/ mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
P74 (B1:8)	-	-	-	-	-	-	-	-
P65 (B1:8)	BOR	7.6/25	1825	48	1975	52	3800	End Bearing
P91 (Vert.)	BOR	6.8/25	1000	30	2300	70	3300	End Bearing
P126 (Vert.)	-	-	-	-	-	-	-	-
P120 (Vert.)	BOR	10/40	2000	61	1300	39	3300	Friction
P4 (Vert.)	-	-	-	-	-	-	-	-
P6 (Vert.)	-	-	-	-	-	-	-	-

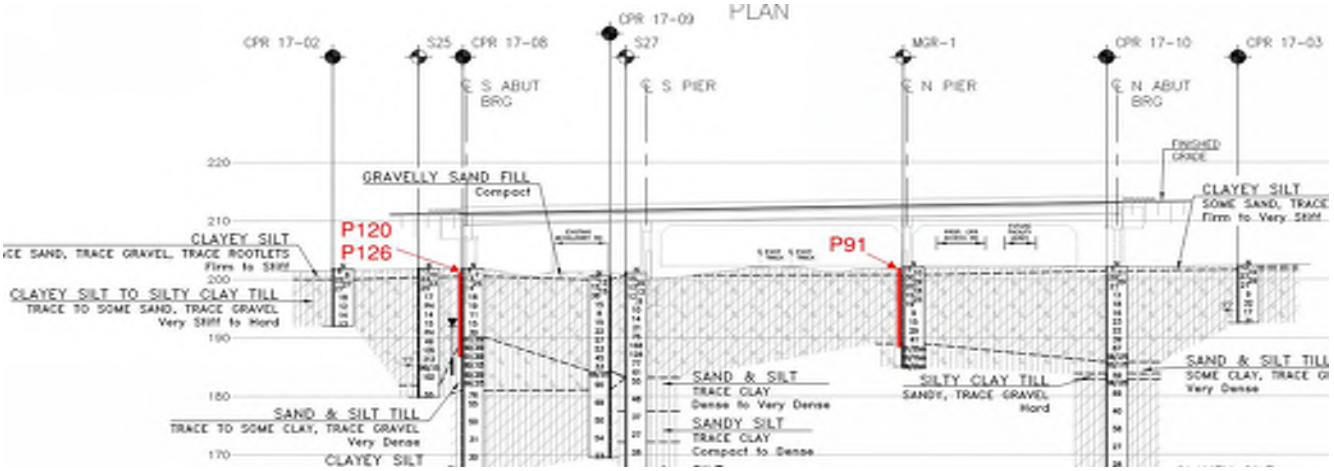
Axial Geotechnical Resistances from FIDR

Location	Pile Tip. Elev. (m)	Founding Stratum	Factored ULS (kN)*	Factored SLS (kN)
South Abutment (NBL)	187.0	Very Dense Sand & Silt Till	1200 (HP310x110)	1000 (HP310x110)
South Pier (NBL)	184.0			
North Pier (NBL)	185.0		1500 (HP360x174)	1300 (HP360x174)
North Abutment (NBL)	187.0			
North Abutment (SBL)	188.0		1200 (HP310x110)	1000 (HP310x110)
South Pier (SBL)	184.0			
North Pier (SBL)	185.0		1500 (HP360x174)	1300 (HP360x174)
South Abutment (SBL)	186.0			

Soil Stratigraphy at Pile Locations



PLAN

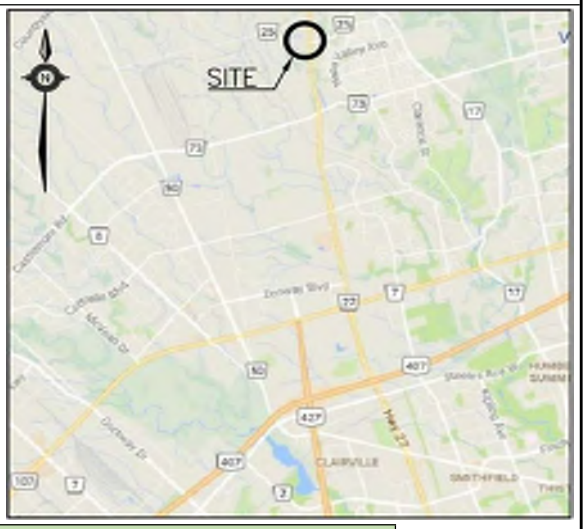


Site No:	19	Project:	Major Mackenzie Drive Overpass (Structure B18)-NBL & SBL

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Thurber. Foundation Investigation and Design Report (100% Submission), Highway 427 Expansion, Major Mackenzie Drive Overpass (Structure B18), Oct. 11, 2018. Report No. H427-5-FND-REP-005-D
Contract Dwgs	Structural Drawings Provided
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Major Mackenzie Drive Overpass, North Abutment. Project Number BRM-00607283-A0 (Oct. 25, 2019)
Pile Logs	P5-B18-S.Abut-034-B-010, P5-B18-034-B-009

Pile I.D.	Location	Soil Stratum	Pile Type
P32 (Vert.)	North Abutment	Cohesive	End Bearing
P19 (Vert.)	North Abutment	Cohesive	End Bearing



Vert. Vertical Pile
BOR Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
P32 (Vert.)	North Abutment	HP310 x 110	25.24	-	16.25	43.1	Yes	8.38	205	188.75
P19 (Vert.)	North Abutment		25.24	-	16.2	43.1	Yes	8.38	204.9	188.7

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
P32 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110	Terex HC110-1 Crawler Crane	Fixed	Oct. 7, 2019
P19 (Vert.)					No				Oct. 1, 2019

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
P32 (Vert.)	Oct. 8, 2019	BOR	6072	Oct. 8, 2019	BOR	7	48.0	36	43.6	3500	248	2700
P19 (Vert.)	Oct. 8, 2019	BOR	6481	Oct. 8, 2019	BOR	10	45.0	37	40.9	3430	243	2800

CAPWAP

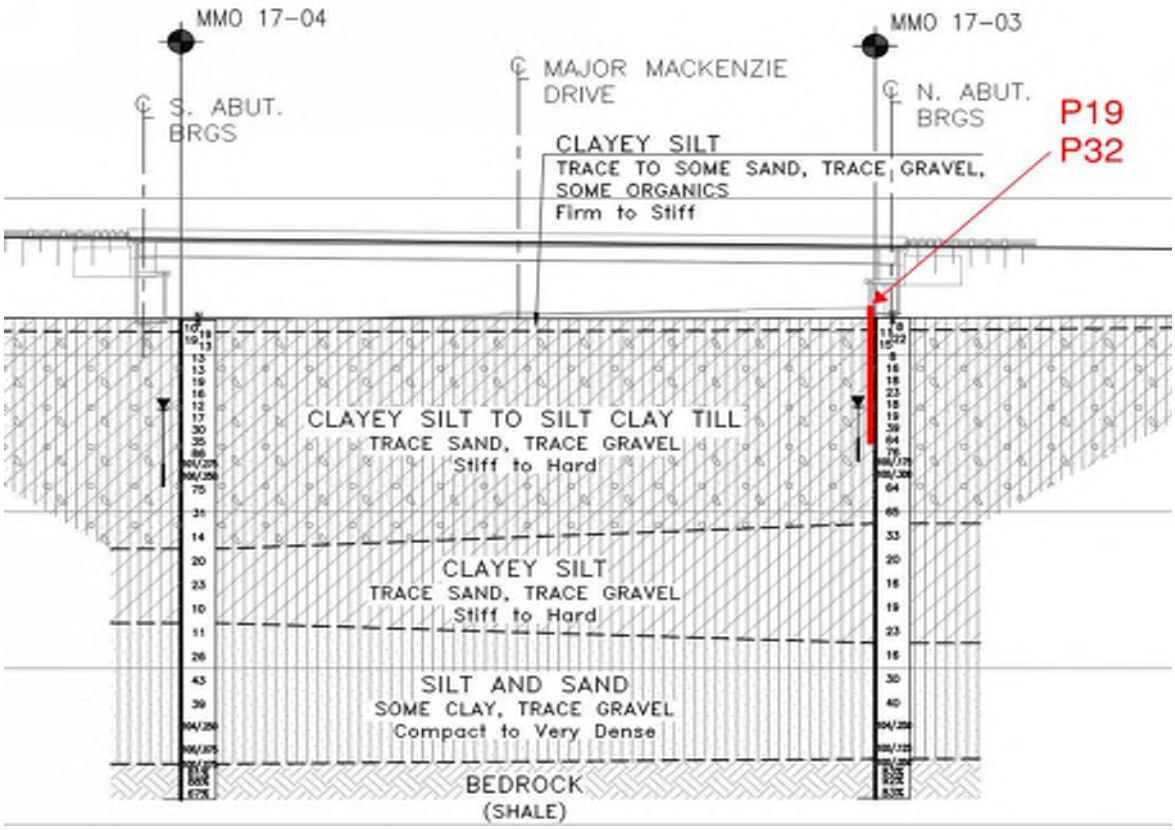
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
P32 (Vert.)	BOR	10/36	1100	41	1600	59	2700	End Bearing
P19 (Vert.)	-	-	-	-	-	-	-	-

Axial Geotechnical Resistances for HP310 x 110 from FIDR

Location	Pile Tip. Elev. (m)	Founding Stratum	Factored ULS (kN)*	Factored SLS (kN)
South Abutment	186.0	Hard clayey silt to silty clay till	1000	800
North Abutment	186.0		1000	800

* Target factored ULS resistance of 800kN was considered as per PDA report.

Soil Stratigraphy at Pile Locations



Site No:	20	Project:	Major Mackenzie Drive over West Robinson Creek

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Thurber. Foundation Investigation and Design Report (100% Submission), Highway 427 Expansion, Major Mackenzie Drive Over West Robinson Creek (Structure B19), May. 29, 2019. Report No. H427-5A-FND-REP-001-D
Contract Dwgs	Structural Drawings Provided
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Major Mackenzie Drive Over West Robinson Creek, East Abutment. Project Number BRM-00607283-A0 (Sep. 6, 2019)
PDA Report	EXP. Dynamic Testing of Piles, Highway 427 Expansion, Major Mackenzie Drive Over West Robinson Creek, West Abutment, March 8 and 12, 2019 Visits. Project Number BRM-00607283-A0 (Oct. 25, 2019)
Pile Logs	P5A-B19-034-C-001, P5A-B19-034-C-002, P5A-B19-STG 03-034-C-005, P5A-B19-STG 03-034-C-006

Pile I.D.	Location	Soil Stratum	Pile Type
30 (Vert.)	East Abutment	Cohesionless	End Bearing
35 (Vert.)	East Abutment	Cohesionless	End Bearing
1 (Vert.)	West Abutment	Cohesionless	Friction/End Bearing
11 (Vert.)	West Abutment	Cohesionless	Friction/End Bearing
11 (Vert.)	West Abutment	Cohesionless	Friction/End Bearing
11 (Vert.)	West Abutment	Cohesionless	Friction/End Bearing
10 (Vert.)	West Abutment	Cohesionless	Friction/End Bearing
8 (Vert.)	West Abutment	Cohesionless	End Bearing

Vert.	Vertical Pile
BOR	Beginning of Restrike
BO2R	Beginning of 2nd Restrike
EOR	End of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
30 (Vert.)	East Abutment	HP310 x 110	15.337	-	11.5	26.2	Yes	-	198.2	186.7
35 (Vert.)	East Abutment		15.337	-	11.5	26.2	Yes	-	198.3	186.8
1 (Vert.)	West Abutment		15.29	-	13	26.1	Yes	-	199.4	186.4
11 (Vert.)	West Abutment		15.29	-	12.3	26.1	Yes	-	200.6	188.3
11 (Vert.)	West Abutment		15.29	-	13.5	26.1	Yes	-	200.6	187.1
11 (Vert.)	West Abutment		15.29	-	13.5	26.1	Yes	-	200.6	187.1
10 (Vert.)	West Abutment		15.29	-	13	26.1	Yes	-	200.6	187.6
8 (Vert.)	West Abutment		15.29	-	10.6	26.1	Yes	-	200.5	189.9

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
30 (Vert.)	Berminghammer B-32	Diesel Hammer	3200	840	No	110	Terex HC110-1 Crawler Crane	Fixed	Aug. 22, 2019
35 (Vert.)					No				Aug. 23, 2019
1 (Vert.)					No				Mar. 7, 2019
11 (Vert.)					No				Mar. 7, 2019
11 (Vert.)					No				Mar. 7, 2019
11 (Vert.)					No				Mar. 7, 2019
10 (Vert.)					No				Mar. 11, 2019
8 (Vert.)					No				Mar. 8, 2019

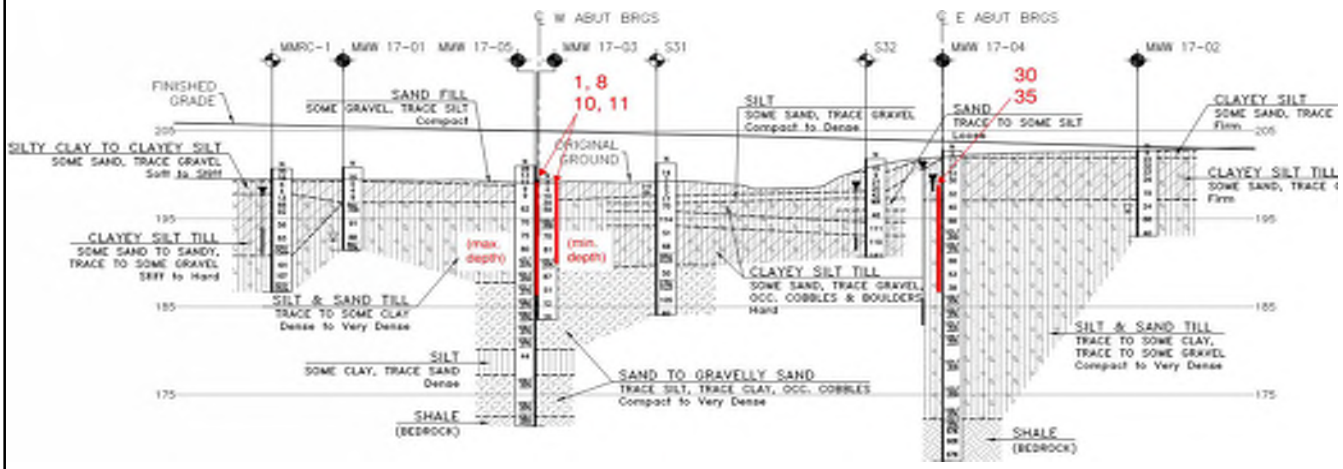
Hiley Test Results				Pile Driving Analyzer Data								
Pile No.	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
30 (Vert.)	Aug. 26, 2019	BOR	4552	Aug. 26, 2019	BOR	3.8	44.0	37	40.0	3720	264	2800
35 (Vert.)	Aug. 26, 2019	BOR	5636	Aug. 26, 2019	BOR	4.5	44.0	37	40.0	3500	248	2900
1 (Vert.)	Mar. 8, 2019	BOR	5881	Mar. 8, 2019	BOR	3.3	51.0	36	46.4	3700	263	2850
11 (Vert.)	Mar. 8, 2019	BOR	4103	Mar. 8, 2019	BOR	2.0	49.0	37	44.5	3590	255	2300
11 (Vert.)	Mar. 8, 2019	EOR	4094	Mar. 8, 2019	EOR	2.0	54.0	36	49.1	3770	267	2450
11 (Vert.)	Mar. 12, 2019	BO2R	4979	Mar. 12, 2019	BO2R	3.6	50.0	36	45.5	3640	258	2850
10 (Vert.)	Mar. 12, 2019	BOR	4099	Mar. 12, 2019	BOR	3.0	46.0	37	41.8	3670	260	2800
8 (Vert.)	Mar. 12, 2019	BOR	9327	Mar. 12, 2019	BOR	3.7	44.0	37	40.0	3430	244	2850

CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
30 (Vert.)	BOR	7/46	1000	36	1800	64	2800	End Bearing
35 (Vert.)	-	-	-	-	-	-	-	-
1 (Vert.)	BOR	10/75	1350	47	1500	53	2850	End Bearing
11 (Vert.)	-	-	-	-	-	-	-	-
11 (Vert.)	-	-	-	-	-	-	-	-
11 (Vert.)	-	-	-	-	-	-	-	-
10 (Vert.)	-	-	-	-	-	-	-	-
8 (Vert.)	-	-	-	-	-	-	-	-

Axial Geotechnical Resistances for HP310 x 110 from FIDR

Location	Pile Tip. Elev.	Founding Stratum	Factored ULS (kN)	Factored SLS (kN)
West Abutment	186.0	V. Dense Sand and Gravel	1400	1100
East Abutment	186.0	V. Dense Sand and Silt Till	1400	1100

Soil Stratigraphy at Pile Locations



Site No:	21	Project:	Hwy 400 - Anne Street Underpass

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Thurber. Anne Street Underpass, Highway 400, City of Barrie, Ontario, Site 30-347, G.W.P. 2504-17-00, Geocress No. 30D-739. June 9, 2020, File: 22424
Contract Dwgs	2020-2132
Pile Load Test Report	N.A.
PDA Report	SACL. Anne Street Underpass Bridge Replacement, Hwy 400, Barrie, Ontario, MTO-2020-2132, Dynamic Testing of Piles, Report - 2108055-1. August 25, 2021
PDA Report	SACL. Anne Street Underpass Bridge Replacement, Hwy 400, Barrie, Ontario, MTO-2020-2132, Dynamic Testing of Piles, Report - 2108055-2. September 10, 2021
PDA Report	SACL. Anne Street Underpass Bridge Replacement, Hwy 400, Barrie, Ontario, MTO-2020-2132, Dynamic Testing of Piles, Report - 2108055-3. November 5, 2021
PDA Report	SACL. Anne Street Underpass Bridge Replacement, Hwy 400, Barrie, Ontario, MTO-2020-2132, Dynamic Testing of Piles, Report - 2108055-4. November 24, 2021
Pile Logs	No official report, only unsorted files were provided.

Pile I.D.	Location	Soil Stratum	Pile Type
P4 (1:6)	West Abutment	Layered/Cohesive	Friction/End Bearing
P49 (1:12)	West Abutment	Layered/Cohesive	Friction/End Bearing
P56 (1:6)	West Abutment	Layered/Cohesive	Friction/End Bearing
P58 (1:6)	West Abutment	Layered	Friction
P5 (Vert.)	West Abutment	Layered	Friction
P10 (1:6)	West Abutment	Layered	Friction
P16 (1:6)	West Abutment	Layered	Friction
P43 (1:6)	West Abutment	Layered	Friction
P49 (1:12)	West Abutment	Layered	Friction
P4 (Vert.)	East Abutment	Layered	Friction
P5 (B1:6)	East Abutment	Layered	Friction
P30 (B1:6)	East Abutment	Layered	Friction
P36 (B1:6)	East Abutment	Layered	Friction
P60 (Vert.)	East Abutment	Layered	Friction

Vert.	Vertical Pile
B1:#	Battered at # Vertical to 1 Horizontal
EOID	End of Initial Drive
EORD	End of Redriving
BOR	Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
P4 (1:6)	West Abutment	HP310 x 110	18.37	-	16.6	19.8	OPSD 3000.100 pile shoe	-	232.8	216.2
P49 (1:12)	West Abutment		18.37	-	16.5	19.8		-	232.7	216.2
P56 (1:6)	West Abutment		18.39	-	16.9	19.8		-	232.6	215.7
P58 (1:6)	West Abutment		18.37	-	23.5	19.8		-	232.7	209.2
P5 (Vert.)	West Abutment		29.1	-	22	31.4		18.37	232.8	210.8
P10 (1:6)	West Abutment		29.1	-	14.2	31.4		18.37	232.6	218.4
P16 (1:6)	West Abutment		18.37	-	16.9	19.8		-	232.6	215.7
P43 (1:6)	West Abutment		18.37	-	16.85	19.8		-	232.6	215.75
P49 (1:12)	West Abutment		29.1	-	16.6	31.4		18.37	232.7	216.1
P4 (Vert.)	East Abutment		27.6	-	24.2	29.8		19.2	231.3	207.1
P5 (B1:6)	East Abutment		28.25	-	24.5	30.5		19.85	231.3	206.8
P30 (B1:6)	East Abutment		28.17	-	24.15	30.4		19.87	231.3	207.15
P36 (B1:6)	East Abutment		28.39	-	26.55	30.6		19.87*	231.3	204.75
P60 (Vert.)	East Abutment		27.56	-	26.3	29.7		19.14	231.3	205

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
P4 (1:6)	Berminghammer B-32	Diesel Hammer	3200	840	No	110	Terex HC 110 Hydraulic Crawler Crane	Fixed	Aug. 19, 2021
P49 (1:12)					No				Aug. 18, 2021
P56 (1:6)					No				Aug. 17, 2021
P58 (1:6)					No				Aug. 17, 2021
P5 (Vert.)					No				Aug. 31, 2021
P10 (1:6)					No				Aug. 20, 2021
P16 (1:6)					No				Aug. 23, 2021
P43 (1:6)					No				Aug. 23, 2021
P49 (1:12)					No				Aug. 18, 2021
P4 (Vert.)					No				Nov. 3, 2021
P5 (B1:6)					No				Nov. 3, 2021
P30 (B1:6)					No				Nov. 3, 2021
P36 (B1:6)					No				Nov. 4, 2021
P60 (Vert.)					No				Nov. 12, 2021

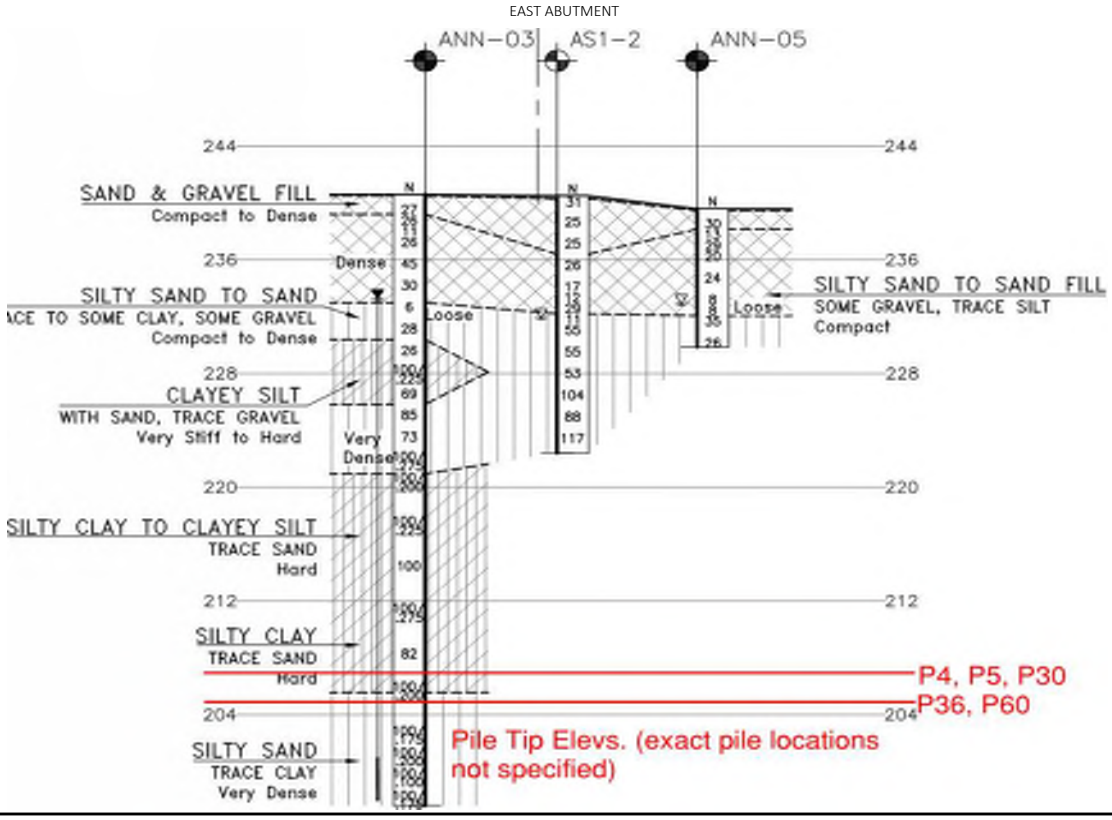
*Note: Not written in pile logs, assumed based on nearby pile in same pile group.

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	ETR (%)	FMX (kN)	CSX (Mpa)	CSB (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
P4 (1:6)	Aug. 19, 2021	EOID	3890	Aug. 24, 2021	EORD	5.0	37.6	34	3218	228	134	2175
P49 (1:12)	Aug. 18, 2021	EOID	4363	Aug. 24, 2023	EORD	9.0	48.3	44	3836	272	210	2900
P56 (1:6)	Aug. 18, 2021	EOID	6765	Aug. 24, 2024	EORD	25.0	45.8	42	3501	248	214	3100
P58 (1:6)	Aug. 17, 2021	EOID	5300	Aug. 24, 2025	EORD	23.0	45.5	41	3504	249	216	3200
P5 (Vert.)	Aug. 31, 2021	EOID	4830	Sep. 9, 2021	BOR	25.0	52.6	48	3823	271	268	3751
P10 (1:6)	Sept. 9, 2021	BOR	4744	Sep. 9, 2021	BOR	3.0	34.8	32	3121	221	136	1600
P16 (1:6)	Aug. 23, 2021	EOID	3938.4	Sep. 9, 2021	BOR	6.0	39.2	36	3283	233	206	2700
P43 (1:6)	Aug. 23, 2021	EOID	4557	Sep. 9, 2021	BOR	5.0	44.7	41	3457	245	217	3100
P49 (1:12)	Sep. 9, 2021	BOR	5159	Sep. 9, 2021	BOR	9.0	43.1	39	3460	245	228	2700
P4 (Vert.)	Nov. 3, 2021	EOID	5155	Nov. 4, 2021	BOR	>25	46.5	42	3416	243	222	3450
P5 (B1:6)	Nov. 2, 2021	EOID	4918	Nov. 4, 2021	BOR	>25	43.2	39	3435	244	219	3460
P30 (B1:6)	Nov. 3, 2021	EOID	5002	Nov. 4, 2021	BOR	No movement	40.3	37	3313	236	219	3420
P36 (B1:6)	Nov. 4, 2021	EOID	4528	Nov. 4, 2021	EOID	>25	37.5	34	3143	223	208	2850
P60 (Vert.)	Nov. 12, 2021	EOID	4205	Nov. 23, 2021	BOR	No movement	47.6	43	3572	253	228	3411

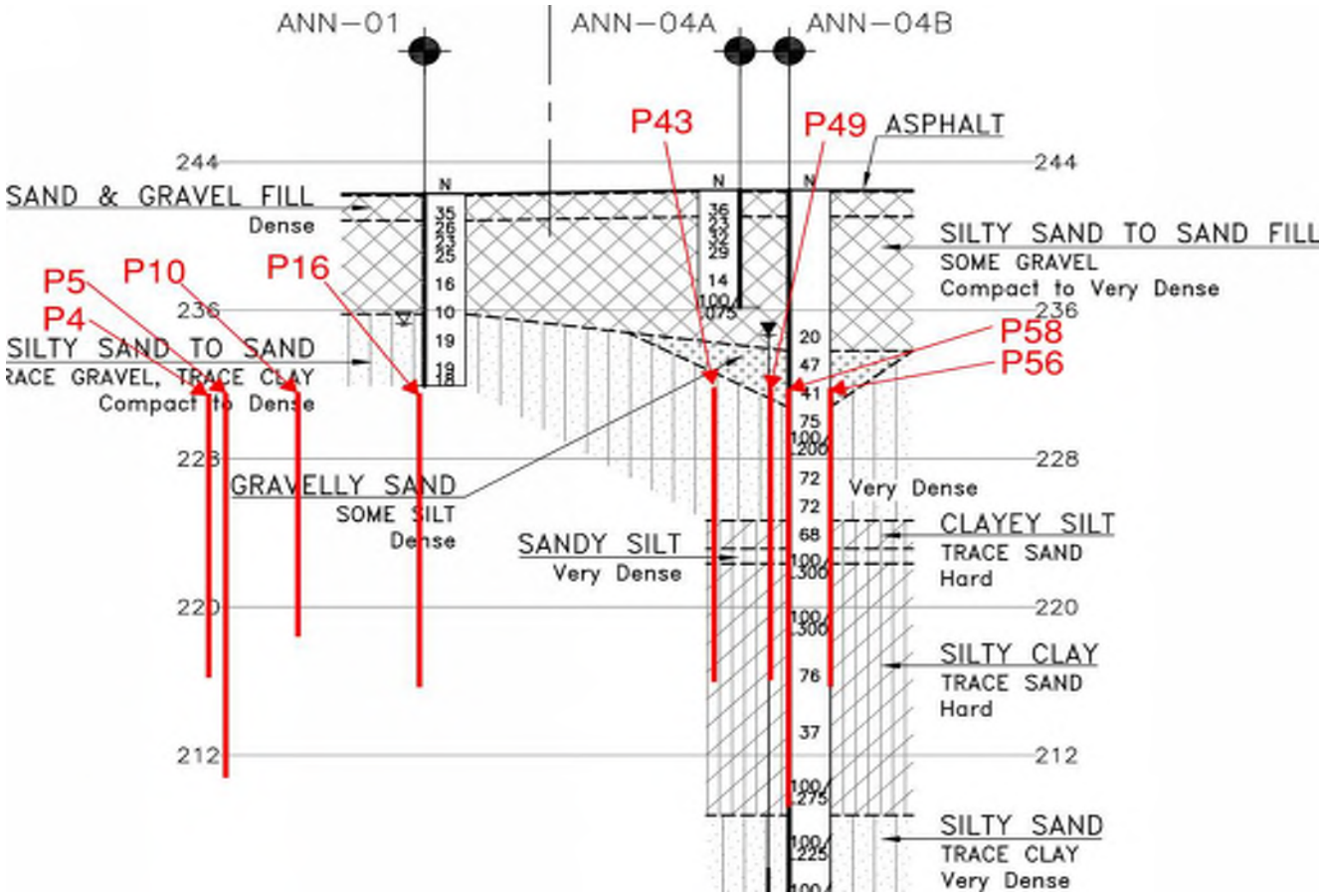
CAPWAP									Pile Design Capacity, FIDR (kN)	
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type	Factored ULS	SLS for 25 mm Settlement
P4 (1:6)	End of redriving	5	952	44	1223	56	2175	End Bearing	1600*	1400
P49 (1:12)	End of redriving	9	1425	49	1475	51	2900	End Bearing		
P56 (1:6)	End of redriving	25	1744	56	1356	44	3100	Friction		
P58 (1:6)	End of redriving	23	2050	64	1150	36	3200	Friction		
P5 (Vert.)	BOR	25	3303	88	448	12	3751	Friction		
P10 (1:6)	BOR	3	1100	69	500	31	1600	Friction		
P16 (1:6)	BOR	6	1950	72	750	28	2700	Friction		
P43 (1:6)	BOR	5	2550	82	550	18	3100	Friction		
P49 (1:12)	BOR	9	1800	67	900	33	2700	Friction		
P4 (Vert.)	BOR	>25	2600	75	850	25	3450	Friction		
P5 (B1:6)	BOR	>25	3110	90	350	10	3460	Friction		
P30 (B1:6)	BOR	No movement	3120	91	300	9	3420	Friction		
P36 (B1:6)	EOID	>25	2500	88	350	12	2850	Friction		
P60 (Vert.)	BOR	No movement	3140	92	271	8	3411	Friction		

*Note = ULS design capacity during PDA tests was 1550 kN.

Soil Stratigraphy at Pile Locations



WEST ABUTMENT

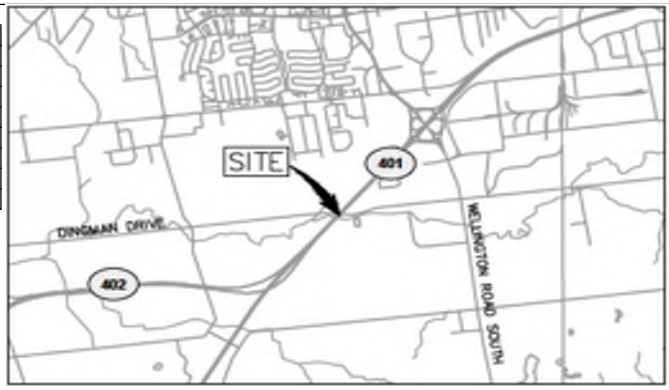


Site No:	22	Project:	Highway 401 & Dingham Drive Underpass

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Golder. Highway 401/Dingham Drive Underpass Replacement (Site No. 19X-0368/B0), London, Ontario. MTO GWP 3025-18-00, Assignment No. 3018-E-0011. Geocres No.: 40I14-194. April 26, 2021
Contract Dwgs	2020-3062
Pile Load Test Report	N.A.
PDA Report	(Subsurface Geotech Inc.) MTO 2020-3062, Dingham Drive & HWY 401, London, ON. PDA Report 1 - Rev. 1, SSG Project # 11142104. September 20, 2021
PDA Report	(Subsurface Geotech Inc.) MTO 2020-3062, Dingham Drive & HWY 401, London, ON. PDA Report 2, SSG Project # 11142104. September 21, 2021
PDA Report	(Subsurface Geotech Inc.) MTO 2020-3062, Dingham Drive & HWY 401, London, ON. PDA Report 3, SSG Project # 11142104. October 12, 2021
PDA Report	(Subsurface Geotech Inc.) MTO 2020-3062, Dingham Drive & HWY 401, London, ON. PDA Report 4, SSG Project # 11142104. October 14, 2021
Pile Logs	No official report, pile logs provided either in PDA reports or unsorted PDF files

Pile I.D.	Location	Soil Stratum	Pile Type
SA4 (EOID)	South Abutment	Cohesive	Friction/End Bearing
SA12 (EOID)	South Abutment	Cohesive	Friction/End Bearing
SA4 (BOR)	South Abutment	Cohesive	Friction
SA12 (BOR)	South Abutment	Cohesive	Friction
PN13	Center Pier	Cohesive	Friction/End Bearing
PN14	Center Pier	Cohesive	Friction/End Bearing
PN16	Center Pier	Cohesive	Friction
PN17	Center Pier	Cohesive	Friction



Vert.	Vertical Pile
B1:10	Battered at 10 Vertical to 1 Horizontal
EOID	End of Initial Drive
BOR	Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
SA4 (Vert.)	South Abutment	HP310 x 132	43	-	36	55.7	Hardbite 7780-B driving shoe (central, assume for SA)	13.87/ 27.65	259.9	223.9
SA12 (Vert.)	South Abutment		43	-	35	55.7		13.87/ 27.65	259.9	224.9
SA4 (Vert.)	South Abutment		43	-	36	55.7		13.87/ 27.65	259.9	223.9
SA12 (Vert.)	South Abutment		43	-	35	55.7		13.87/ 27.65	259.9	224.9
PN13 (B1:10)	Center Pier	HP310 x 110	36.85	-	31.1	47.7		18.4	258.8	227.7
PN14 (B1:10)	Center Pier		37.2	-	31.8	48.2		18.4	258.8	227
PN16 (B1:10)	Center Pier		36.8	-	31	47.7		18.4	256.6	225.6
PN17 (B1:10)	Center Pier		36.8	-	31	47.7		18.4	256.6	225.6

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
SA4	Berminghammer B-32	Diesel Hammer	3200	600	No	110	Crane	Fixed	Oct. 8, 2021
SA12					No				Oct. 8, 2021
SA4					No				Oct. 8, 2021
SA12					No				Oct. 8, 2021
PN13					No				Sep. 17, 2021
PN14					No				Sep. 17, 2021
PN16					No				Sep. 9, 2021
PN17					No				Sep. 9, 2021

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
SA4	Oct. 8, 2021	EOID	4457	Oct. 8, 2021	EOID	-	38.0	-	35	3463	215	2440
SA12	Oct. 8, 2021	EOID	4787	Oct. 8, 2021	EOID	-	39.0	-	35	3440	214	2480
SA4	Oct. 13, 2021	BOR	4401	Oct. 13, 2021	BOR	-	38.4	-	35	3547	220	2900
SA12	Oct. 13, 2021	BOR	4495	Oct. 13, 2021	BOR	-	38.2	-	35	3494	217	2920
PN13	Sep. 17, 2021	EOID	4790	Sep. 17, 2021	EOID	-	45.6	-	41	3447	246	2455
PN14	Sep. 17, 2021	EOID	4623	Sep. 17, 2021	EOID	-	42.2	-	38	3464	242	2430
PN16	Sep. 9, 2021	EOID	5996	Sep. 9, 2021	EOID	-	35.6	-	32	2997	212	2490
PN17	Sep. 9, 2021	EOID	3837	Sep. 9, 2021	EOID	-	40.7	-	37	3250	230	2510

CAPWAP

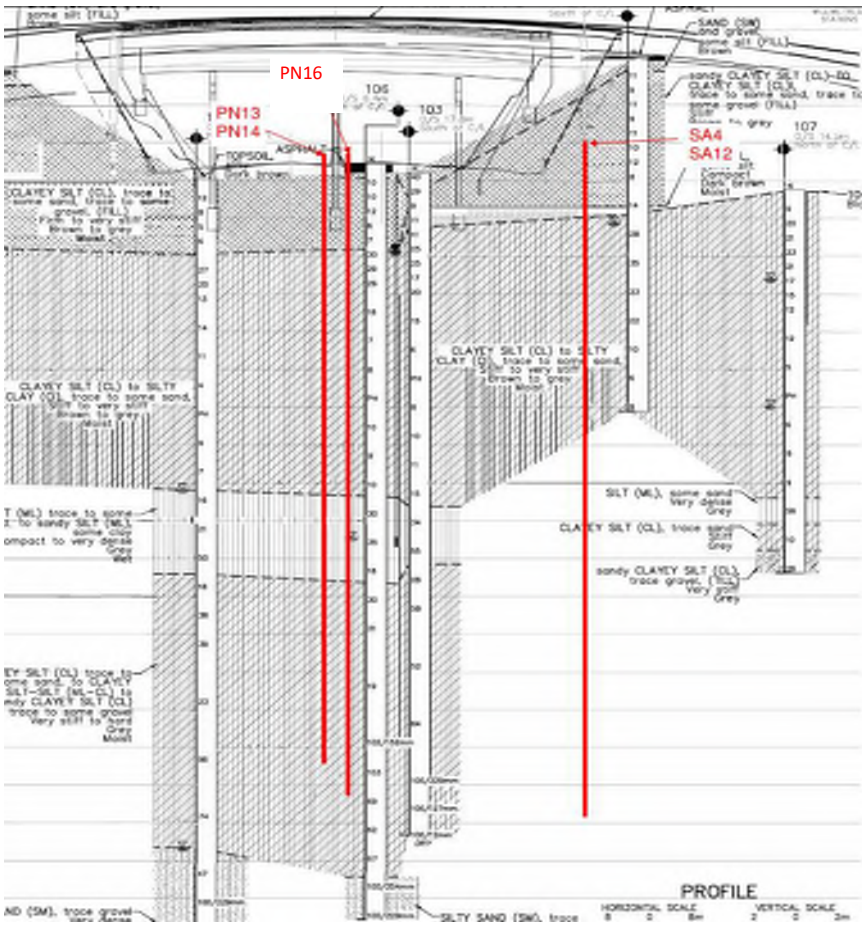
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
SA4	EOID	-	1250	51	1190	49	2440	Friction
SA12	EOID	-	1310	53	1170	47	2480	Friction
SA4	BOR	-	1810	62	1090	38	2900	Friction
SA12	BOR	-	1820	62	1100	38	2920	Friction
PN13	EOID	-	1105	45	1350	55	2455	End Bearing
PN14	EOID	-	1050	43	1380	57	2430	End Bearing
PN16	EOID	-	1790	72	700	28	2490	Friction
PN17	EOID	-	1480	59	1030	41	2510	Friction

Pile Design Axial Resistance as per FIDR

Location	Pile Type	Founding Strata	Tip Elev.	Factored ULS* (kN)	SLS at 25 mm Settlement (kN)
North Abutment	HP310 x 110	Very Dense Sand	220	1700	SLS will be higher than ULS, therefore ULS will govern.
	HP360 x 108			1800	
Pier	HP310 x 110	Hard clayey silt till	228	1600	
	HP360 x 108			1700	
South Abutment	HP310 x 110	Hard clayey silt till	226	1700	
	HP360 x 108			1800	

*Target ULS of 1200 kN used during testing as per PDA report

Soil Stratigraphy at Pile Locations

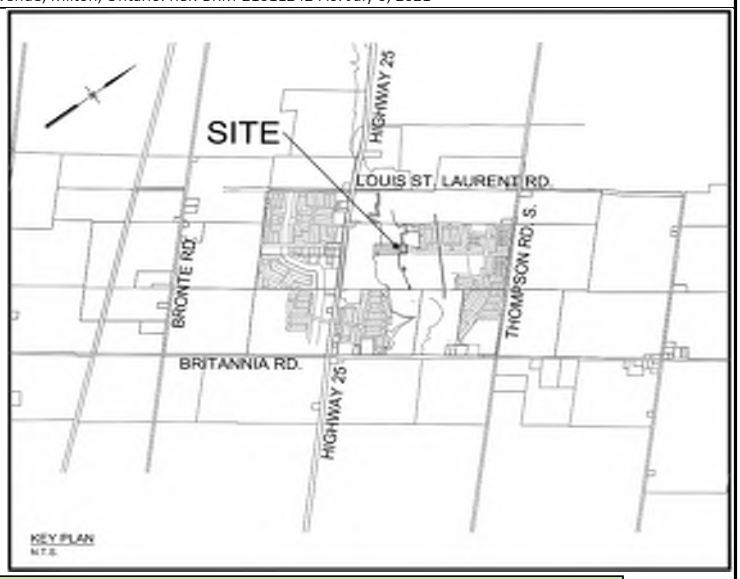


Site No:	23	Project:	16 Ml. Creek Crossing Milton, ON 21011242-A0

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Geotechnical Investigation Report, Proposed Bridge Crossing, Martin Property, East of Regional Road 25, South of Louis St. Laurent Avenue, Milton, Ontario, Ref.: T17699, August 15, 2017 (Shad & Associates Inc.)
Contract Dwgs	16 Mile Creek Crossing, RJB FILE No.: 300040405, Burnside Project No. 300040405, Issued for Tender - Feb. 22, 2021
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, 16 Mile Creek Crossing, Whitlock Avenue, Milton, Ontario. BRM-21011242-A0, July 5, 2021
Pile Logs	EXP. Summary of Pile Installation, 16 Mile Creek Crossing, Whitlock Avenue, Milton, Ontario. Ref: BRM-21011242-A0. July 6, 2021

Pile I.D.	Soil Stratum	Pile Type
EA-6 (B1:3)	Shale Bedrock	End Bearing



B1:3 Battered at 3 Vertical to 1 Horizontal
EOID End of Initial Drive

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
EA-6 (B1:3)	East Abutment	HP310mm x 110 kg/m Steel HP-Section	9.2	-	6.7	9.9	OPSD 3000.100 Driving Shoe	-	186.9	180.2

Hammer Specification / **Pile Driving Details**

Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
EA-6 (B1:3)	Berminghammer B-32	"Direct drive diesel impact hammer"	3200	840	No	110	Crane	Fixed	June 10, 2021

Pile No.	Hiley Test Results			Pile Driving Analyzer Data							
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	EMX (kJ)	Speed (bpm)	ETR (%)	Equivalent Pres. (Blows/25mm) or (Blows/mm)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
EA-6 (B1:3)	June 10, 2021	EOID	9105	June 10, 2021	EOID	37	38	33.6	10	-	3300

CAPWAP

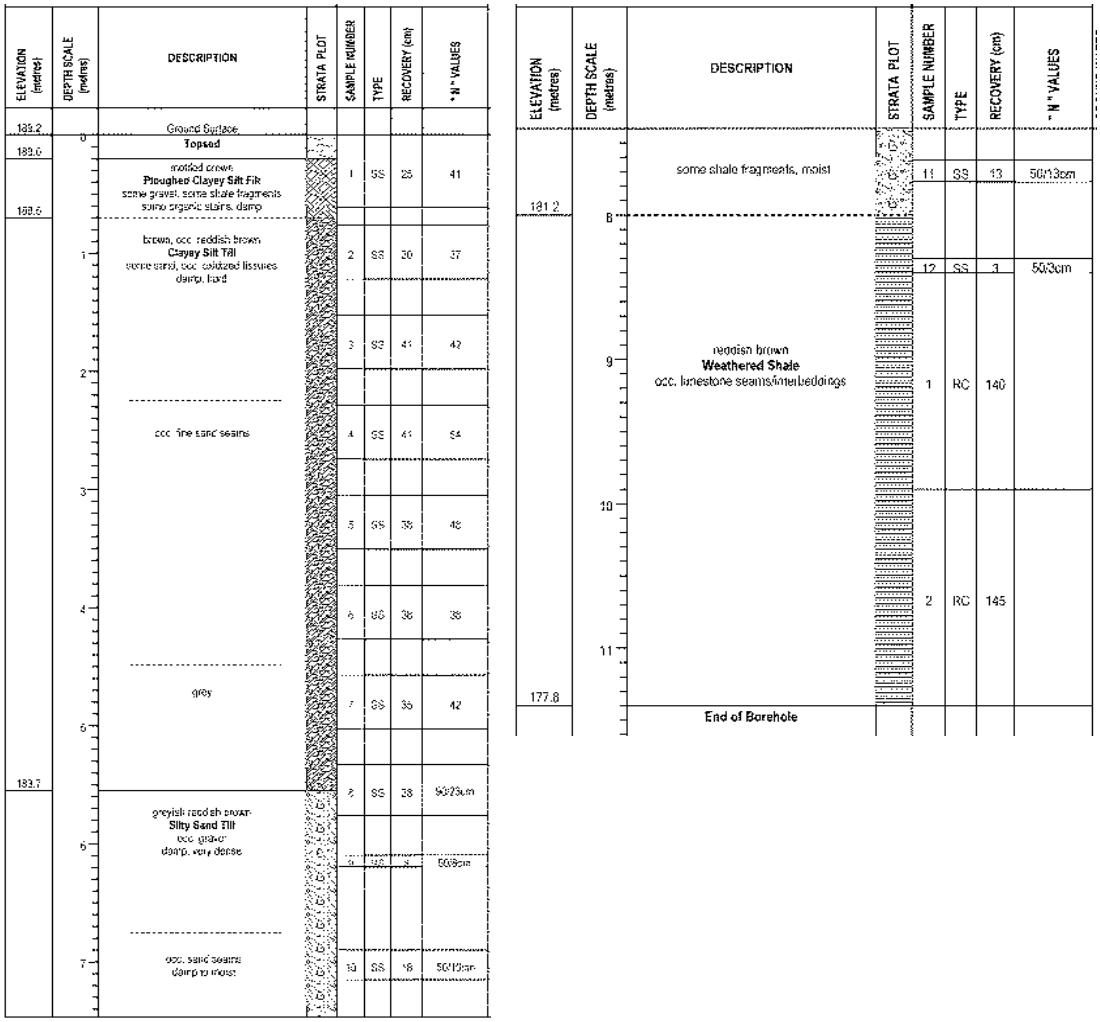
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
EA-6 (B1:3)	EOID	-	850	26	2450	74	3300	End Bearing

Pile Design Capacity

FIDR: Factored ULS 1500 kN/pile, pile tip at approx. Elev. 176.9 m to 181.2 m (hard clayey silt till/very dense silty sand to sandy silt till/shale)

PDA report: Piles at Abutment Designed to Support a Factored Load at ULS of 1350 kN

Soil Stratigraphy at Pile Locations (East Abutment, Borehole BH 305)



Site No:	24	Project:	Bridgepoint Court Bridge Aurora, ON BRM603834-A0

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Supplemental Geotechnical Investigation, Bridge Crossing over Weslie Creek, St. John's Sideroad, Aurora, Ontario. Reference Number: T12369, July 5, 2012 (Shad & Associates Inc.)
Contract Dwgs	Bridgepoint Court Bridge Construction Drawings, Dwg. No. B-001, Sept. 23, 2015
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Analysis of Piles, Bridgepoint Court Bridges, Aurora, Ontario. Project Number BRM-00603834-A0
Pile Logs	No official report, pile logs provided either in PDA reports or unsorted PDF files

Pile I.D.	Soil Stratum	Pile Type
P5 (vert.)	Cohesive	Friction
P5 (vert.)	Cohesive	Friction

Vert. Vertical Pile
BOR Beginning of Restrike
EOR End of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
P5 (vert.)	East Abutment	HP310 x 110	37.75	-	32	40.7	Yes	Spliced, length not specified	255.4	223.4
P5 (vert.)	East Abutment		37.75	-	34.75	40.7	Yes		255.4	220.65

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
P5 (vert.)	Delmag D19-32	Diesel Pile Hammer	1820	705	No	57.6	Crane	Fixed	Apr. 8, 2016
P5 (vert.)					No				Apr. 8, 2016

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
P5 (vert.)	April 11, 2016	BOR	1466	April 11, 2016	BOR	-	18	46	31	2370	169	900
P5 (vert.)	April 11, 2016	EOR	2073	April 11, 2016	EOR	-	22	45	38	2490	178	1700

CAPWAP

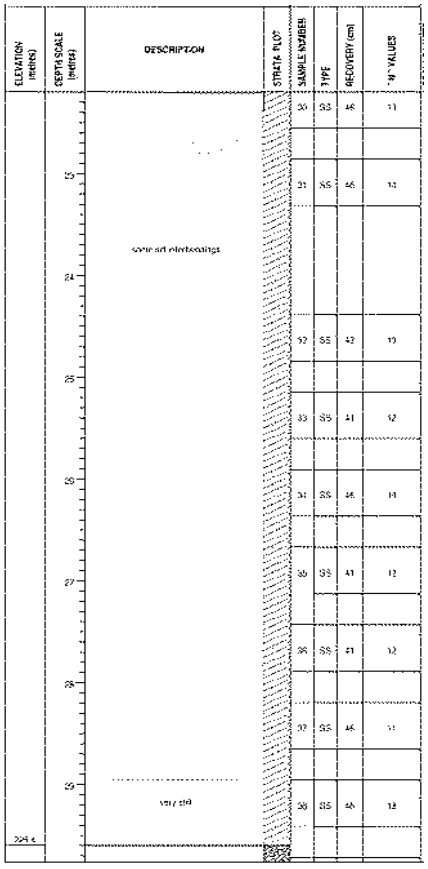
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
P5 (vert.)	BOR	-	-	-	-	-	-	-
P5 (vert.)	EOR	-	1025	60	675	40	1700	Friction

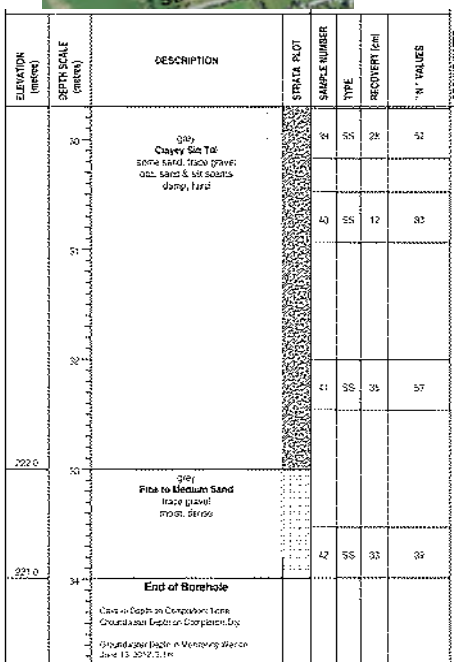
Pile Design Capacity

FIDR: Factored ULS 1000 kN/pile, pile tip at approx. Elev. 222 m to 225 m (hard silty clay till)

Soil Stratigraphy at Pile Locations

EAST ABUTMENT (BH 201)

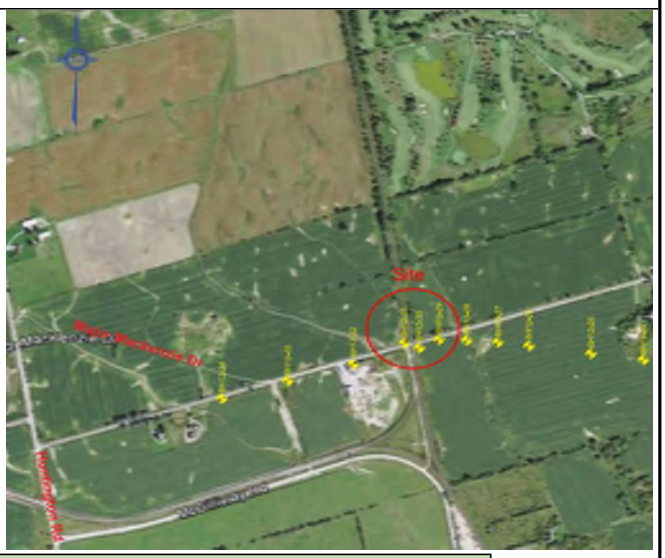




Site No:	25	Project:	CPR Bridge Crossing Major McKenzie Dr Vaughan, ON 607495-A0	Pile Load Test	No
				PDA Test	Yes
				Hiley Test	Yes

Document Type	Document Title
FIDR	Report on Geotechnical Investigation, Widening/Reconstruction and Realignment of Major Mackenzie Drive from Islington Avenue to Huntington Road, Vaughan, Ontario. Project 1359-110, June 4, 2015 (SPL Consultants Ltd.)
Contract Dwgs	-
Pile Load Test Report	N.A.
PDA Report	-
Pile Logs	-

Pile I.D.	Soil Stratum	Pile Type
402 (B1:3)	Layered	Friction
405 (B1:3)	Layered	Friction



B1:3 Battered at 3 Vertical to 1 Horizontal
BOR Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
402 (B1:3)	West Abutment	HP310 x 110	38.2	-	35	41.2	Yes	Spliced (length not specified)	~197	~162
405 (B1:3)	West Abutment		38.2	-	35.1	41.2	Yes		~197	~162

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
402 (B1:3)	Berminghammer B-5505	Diesel hammer	4180	840	No	146	Crane	Fixed	April, 2020
405 (B1:3)					No				April, 2020

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/ 25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
402 (B1:3)	April, 2020	BOR	4115	April, 2020	BOR	-	33	40	23	-	-	1600
405 (B1:3)	April, 2020	BOR	4432	April, 2020	BOR	-	38	40	26	-	-	1700

CAPWAP

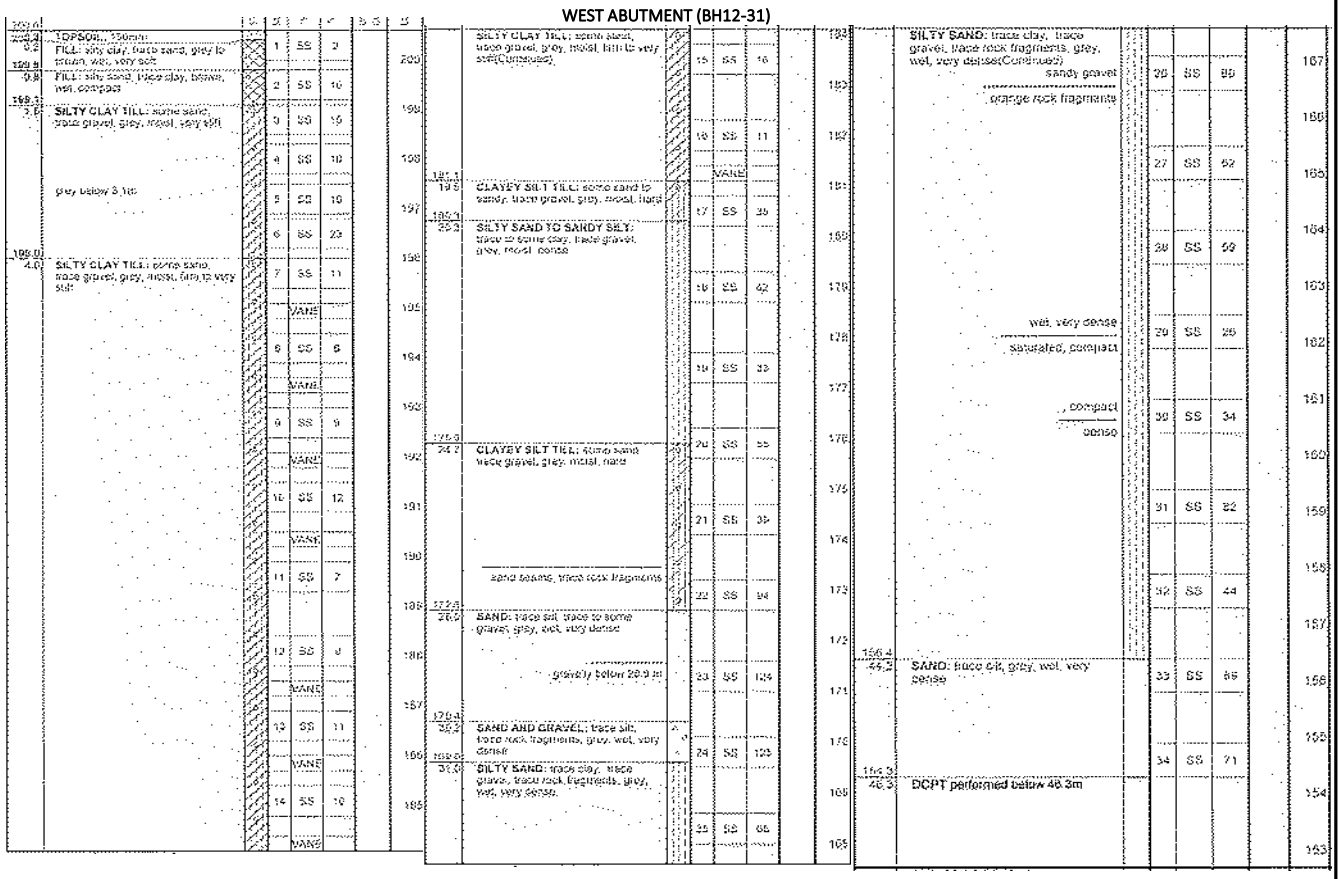
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
No CAPWAP Analysis Available for Tested Piles								

Pile Design Capacity

FIDR: Factored ULS 1500 kN/pile, pile tip at approx. Elev. 160 m (dense to very dense sand or sand and gravel)

Soil Stratigraphy at Pile Locations

WEST ABUTMENT (BH12-31)



Site No:	26	Project:	Gordie Howe Int. Bridge Windsor, ON 607533-B0

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Soil Stratigraphy and ULS Pile Capacity Taken from Item Below
Contract Dwgs	Windsor-Detroit Bridge Authority, Gordie Howe International Bridge, Routh: I-75 Spur Over Detroit River, City of Detroit. Submittal No.: 0360.8, Drawing No. GHIB_MSBR_30A_S, Rev. No.: 2
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, Gordie Howe International Bridge, Canadian Approach Bridge Foundations, Pier 23, December 09, 2021 Visit. Project Number: BRM-00607533-B0, Dec. 14, 2021
Pile Logs	-

Pile I.D.	Soil Stratum	Pile Type
2301 (vert.)	Bedrock	End Bearing

Vert. Vertical Pile
BOR Beginning of Restrike

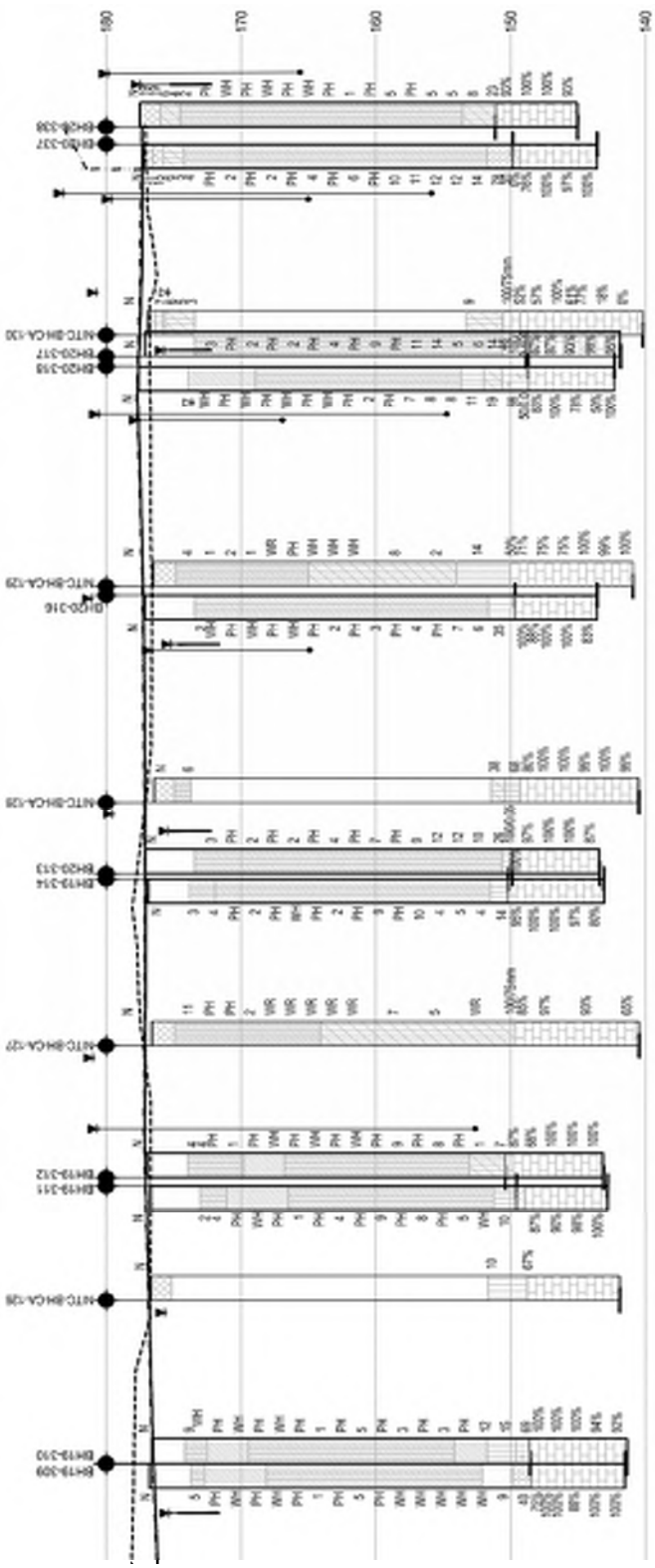
Pile Information										
Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
2301 (vert.)	**Pier 23**	**406 mm OD x 15.9 mm WT CEP (pipe pile)**	**30.5**	**-**	**21.4**	**42.6**	**Yes**	**Spliced, length not specified**	**191.8**	**149.2**

Hammer Specification							Pile Driving Details			Pile Design Capacity
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date	Factored ULS (kN)
2301 (vert.)	**APE D50-52**	**Single Acting Diesel Impact Hammer**	**5000**	**1023**	**No**	**168**	**Crane**	**Fixed**	**Dec. 8, 2021**	2800

	Hiley Test Results			Pile Driving Analyzer Data								
Pile No.	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
2301 (vert.)	**Dec. 9, 2021**	**BOR**	**3989**	**Dec. 9, 2021**	**BOR**	**25**	**111**	**39**	**66**	**-**	**-**	**6600 (mob.)**

CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
2301 (vert.)	**BOR**	**-**	**450**	**7**	**6150**	**93**	**6600**	**End Bearing**

Soil Stratigraphy at Pile Locations



LITHOLOGY SYMBOL AND MATERIAL TYPE

- TOPSOIL
- FILL
- SAND
- SILTY SAND
- SILTY GRAVELLY SAND
- GRAVELLY SAND
- SAND & GRAVEL
- GRAVEL
- SILT
- SANDY SILT
- COBBLES & BOULDERS
- SILTY CLAY
- CLAYEY SILT
- CLAY
- SILTY SAND TILL
- SANDY SILT TILL
- LIMESTONE
- DOLOSTONE

Site No:	27	Project:	Keith Bridge over E. Holland R. Newmarket, ON 600426-A0

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Coffey Geotechnics Inc. Preliminary Geotechnical Investigation, Proposed Keith Bridge, Davis Drive, Newmarket, Ontario. Ref. No GEOBARR00006AA, Dec. 15, 2009
Contract Dwgs	Vivanext, D1, Newmarket, Keith Bridge over East Holland River, Pile Layout. Dwg No. D1-0000-D-004-100, May 2010.
Pile Load Test Report	N.A.
PDA Report	Trow (EXP). Dynamic Analysis of Piles, Keith Bridge over East Holland River, Davis Drive, Newmarket, Ontario. BRM-00600426-A, May 4, 2011
PDA Report	Trow (EXP). Dynamic Analysis of Piles, Report No. 2, Keith Bridge over East Holland River, Davis Drive, Newmarket, Ontario. BRM-00600426-A, June 20, 2011
Pile Logs	EXP. Pile Driving Daily Summary Reports. April 18, 2011 and June 7, 2011

Pile I.D.	Soil Stratum	Pile Type
50 (vert.)	Cohesionless	End Bearing
42 (vert.)	Cohesionless	End Bearing
39 (B1:4)	Cohesionless	End Bearing
48 (vert.)	Cohesionless	End Bearing
38 (vert.)	Cohesionless	End Bearing
56 (vert.)	Cohesionless	End Bearing

Vert. Vertical Pile
B1:4 Battered at 4 Vertical to 1 Horizontal
BOR Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
50 (vert.)	East Abutment	HP310 x 110	21.8		17.8	23.5	OPSD 3000.100	16.8	231.3	213.4
42 (vert.)	East Abutment		16.75		13	18.1		-	231.2	216.1
39 (B1:4)	East Abutment		16.75		14.5	18.1		-	231.1	216.9
48 (vert.)	Pier		16.75	-	12.1	18.1		-	229.2	217.1
38 (vert.)	Pier		16.75	-	10.8	18.1		-	229.2	218.4
56 (vert.)	Pier		16.75	-	11	18.1		-	229.2	218.2

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
50 (vert.)	Berminghammer B-21	"Direct drive diesel impact hammer"	2100	907	No	72	Crane	Fixed	June 7, 2011
42 (vert.)					No				June 7, 2011
39 (B1:4)					No				June 7, 2011
48 (vert.)					No				April 18, 2011
38 (vert.)					No				April 18, 2011
56 (vert.)					No				April 18, 2011

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
50 (vert.)	June 8, 2011	BOR	4240	June 8, 2011	BOR	8	26	37	36.1	-	-	2200
42 (vert.)	June 8, 2011	BOR	5330	June 8, 2011	BOR	15	21	39	29.2	-	-	2000
39 (B1:4)	June 8, 2011	BOR	4555	June 8, 2011	BOR	11	17	41	23.6	-	-	1900
48 (vert.)	April 19, 2011	BOR	4470	April 19, 2011	BOR	8	19	38	26.4	-	-	1800
38 (vert.)	April 19, 2011	BOR	5500	April 19, 2011	BOR	8	18	38	25.0	-	-	1800
56 (vert.)	April 19, 2011	BOR	4830	April 19, 2011	BOR	10	18	38	25.0	-	-	1850

CAPWAP

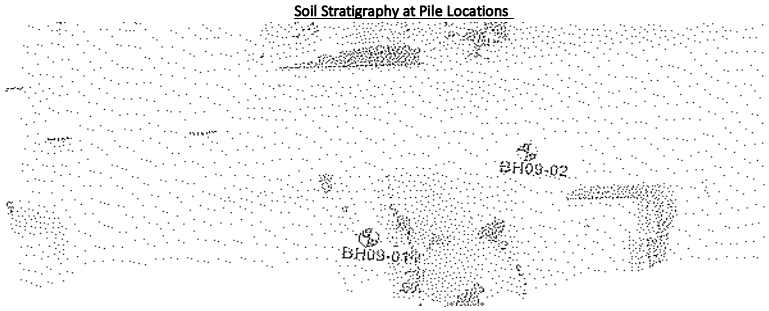
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
50 (vert.)	BOR	-	525	24	1675	76	2200	End Bearing
42 (vert.)	BOR	-	-	-	-	-	-	-
39 (B1:4)	BOR	-	-	-	-	-	-	-
48 (vert.)	BOR	-	-	-	-	-	-	-
38 (vert.)	BOR	-	-	-	-	-	-	-
56 (vert.)	BOR	-	675	36	1175	64	1850	End Bearing

Pile Design Capacity

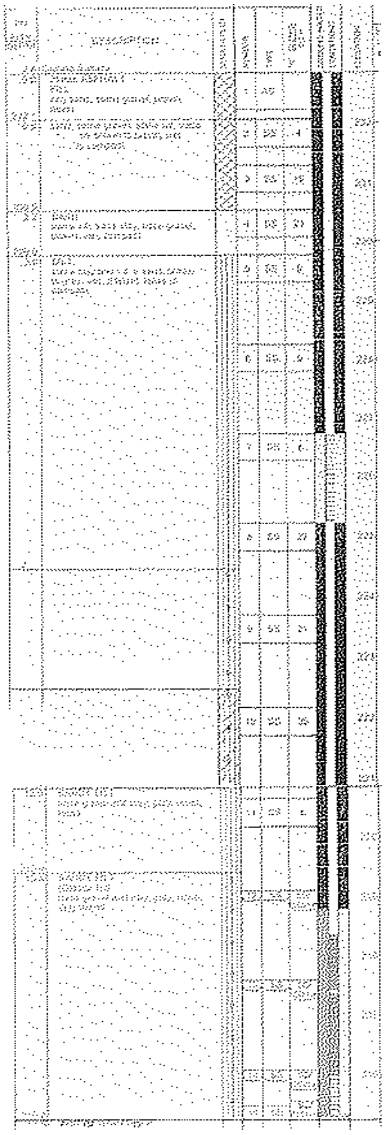
Factored ULS Capacity (kN)	SLS Capacity (kN)	Pile Tip Elev. (m)	Founding Stratum	Location
870*	580	Below 216 m	Dense to very dense sandy silt till	BH09-01
		Below 218 m		BH09-02

*Note: Maximum pile design load stated as 875 kN as per PDA reports

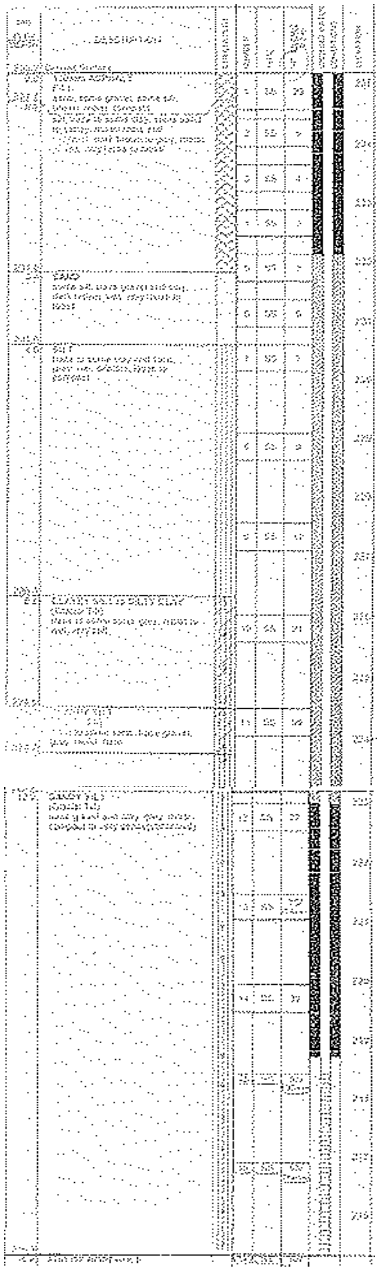
Soil Stratigraphy at Pile Locations



BH09-01



BH09-02

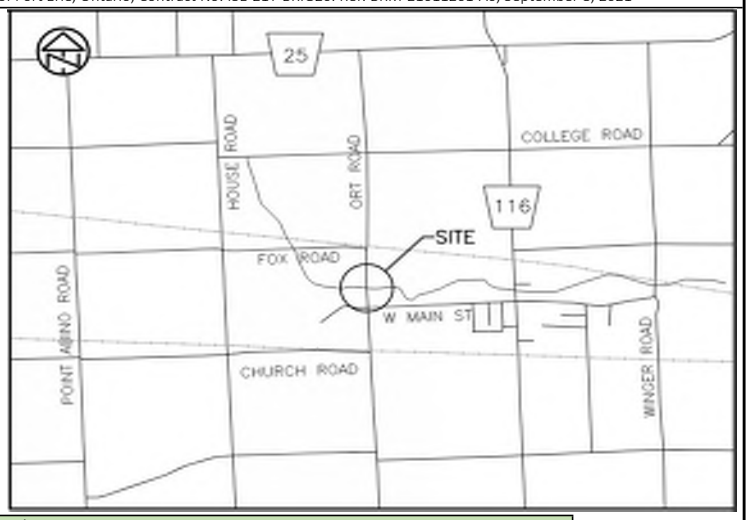


Site No:	28	Project:	Ott Rd. Bridge Fort Erie, ON 21011261-A0

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Geotechnical Investigation, Proposed Bridge Replacement, Ott Road, Fort Erie, Ontario, Project No.: SM 200549-G, Nov. 10, 2020 (Soil-Mat Engineers & Consultants Ltd.)
Contract Dwgs	Ott Road Bridge (S051B) Replacement, Contract No: ISE-21T-BRIG20, March 4, 2021
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, Ott Road Bridge Replacement, Town of Fort Erie, ON, Contract No. ISE-21T-BRIG20. Sept. 8, 2021
Pile Logs	EXP. Summary of Pile Installation, Ott Road Bridge Replacement, Town of Fort Erie, Ontario, Contract No: ISE-21T-BRIG20. Ref: BRM-21011261-A0, September 8, 2021

Pile I.D.	Soil Stratum	Pile Type
S2 (vert.)	Cohesionless	End Bearing



Vert. Vertical Pile
EOID End of Initial Drive

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
S2 (vert.)	**South Abutment**	**HP310 x 110**	**11.5**	**-**	**6.6**	**12.4**	**OPSD 3000.100 Driving Shoe**	**-**	**173.7**	**167.4**

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
S2 (vert.)	**Delmag D19-42**	**"Diesel Hammer"**	**1820**	**600**	**No**	**66**	**Crane**	**Fixed**	**Aug. 25, 2021**

Hiley Test Results				Pile Driving Analyzer Data								
Pile No.	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
S2 (vert.)	**Aug. 25, 2021**	**EOID**	**4770**	**Aug. 25, 2021**	**EOID**	**17**	**35**	**36**	**53**	**-**	**-**	**4200**

CAPWAP

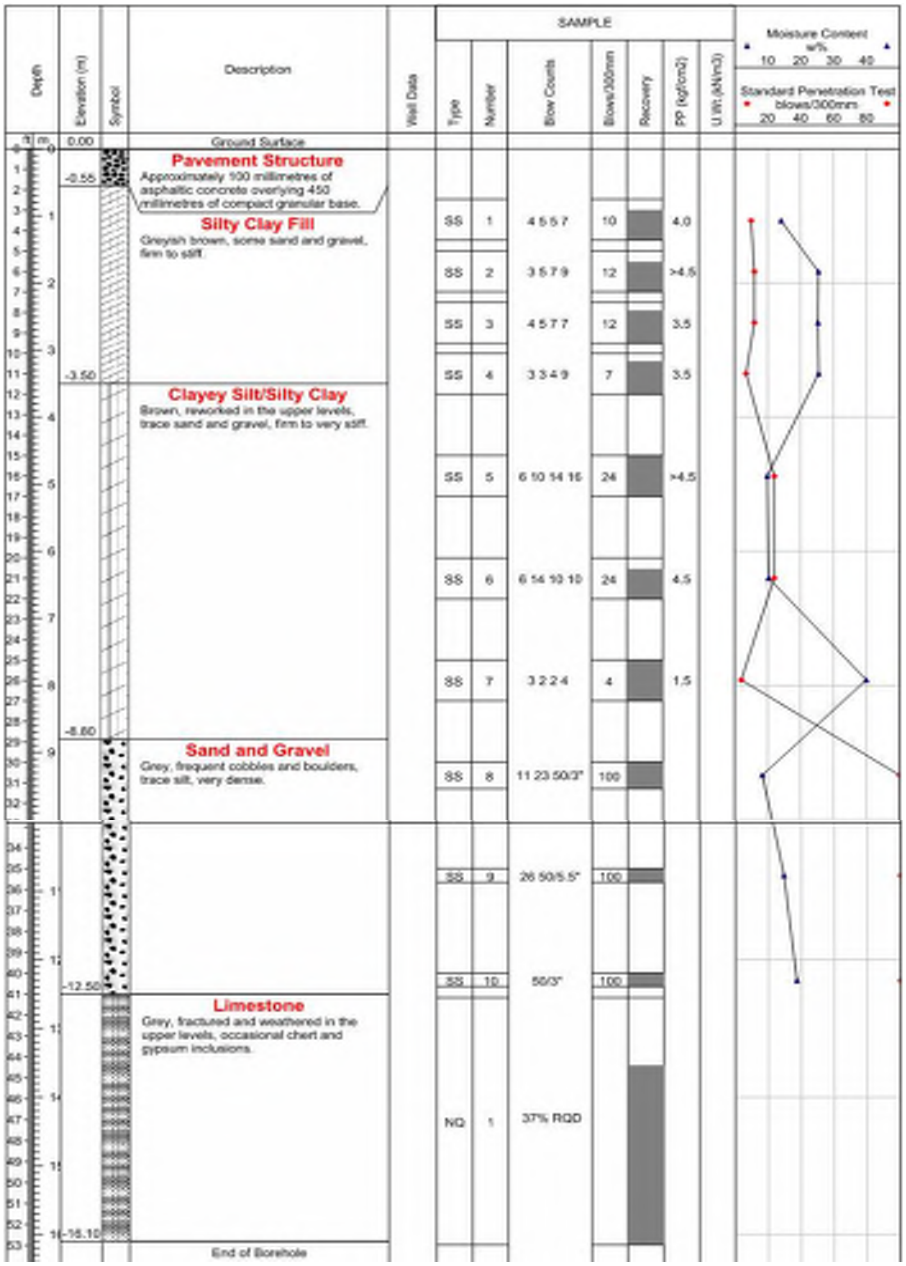
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
S2 (vert.)	**EOID**	**-**	**425**	**10**	**3775**	**90**	**4200**	**End Bearing**

Pile Design Capacity

FIDR: Factored ULS capacity of 1200 kN for HP310x110 pile driven to dense sand and gravel or bedrock.
PDA Report: ULS pile design capacity of 800 kN per PDA report

Soil Stratigraphy at Pile Locations

BH-1

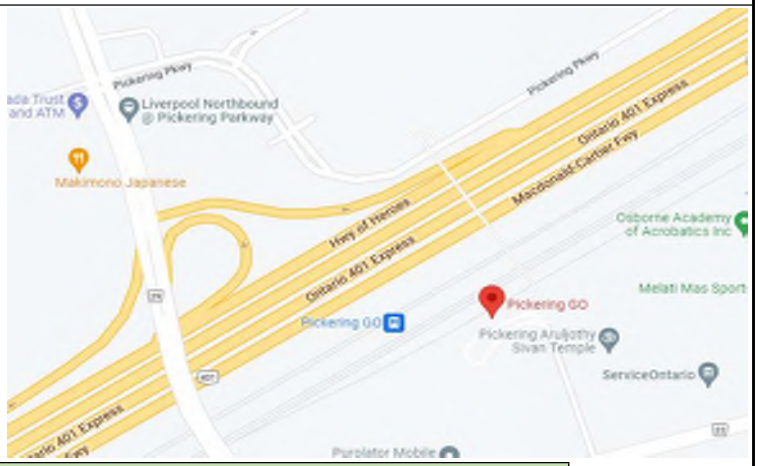


Site No:	29	Project:	GO Station Pedestrian Bridge over Hwy. 401 Pickering, ON 600516-A0

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	-
Contract Dwgs	-
Pile Load Test Report	N.A.
PDA Report	-
Pile Logs	-

Pile I.D.	Soil Stratum	Pile Type
1A (B1:6)	Cohesionless	End Bearing
13 (B1:6)	Cohesionless	End Bearing



B1:6 Battered at 6 Vertical to 1 Horizontal
BOR Beginning of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
1A (B1:6)	-	HP310 x 79	13.7		12.2	10.6	Yes	-	-	-
13 (B1:6)	-		11.4		9.9	8.8	Tes	-	-	-

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
1A (B1:6)	Berminghammer B-32	"Direct drive diesel impact hammer"	3200	840	No	110	Crane*	Fixed*	March, 2011
13 (B1:6)					No				March, 2011

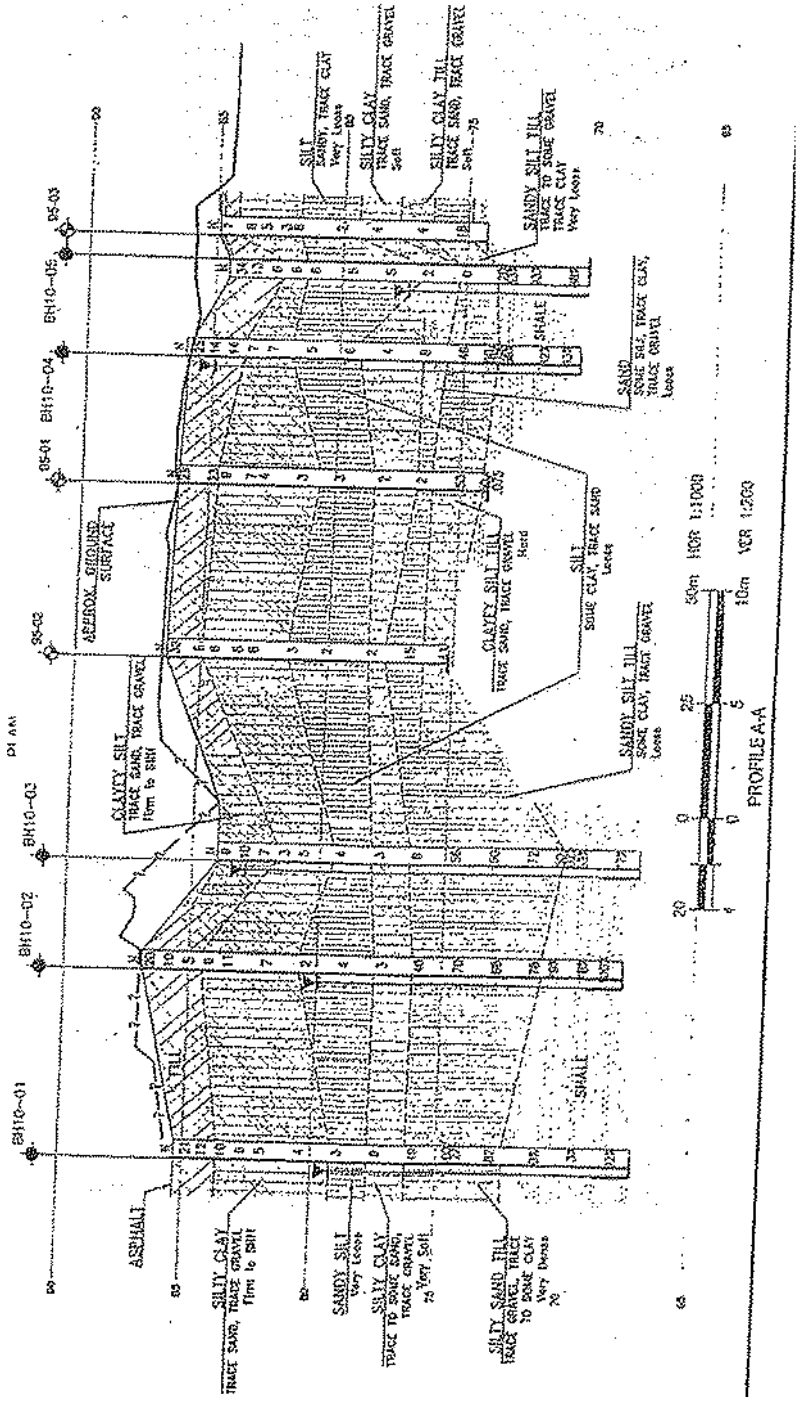
Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
1A (B1:6)	March, 2011	BOR	3274	March, 2011	BOR	-	26	39	24	-	-	1000
13 (B1:6)	March, 2011	BOR	7784	March, 2011	BOR	-	31	40	28	-	-	2300

CAPWAP

Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
1A (B1:6)	BOR	-	875	88	125	13	1000	Friction
13 (B1:6)	BOR	-	300	13	2000	87	2300	End Bearing

*Note: Pile driving equipment and lead assumed based on hammer type used to perform Hiley/PDA test.

Soil Stratigraphy at Pile Locations



Site No:	30	Project:	Weslie Creek Bridge St. Johns Sideroad York Region BRM603942-A0

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	Pavement and Foundation Design Geotechnical Engineering Report, St. John's Sideroad from Bayview Avenue to Highway 404, Regional Municipality of York, Aurora, Ontario, August 2015 (SNC Lavalin)
Contract Dwgs	-
Pile Load Test Report	N.A.
PDA Report	EXP. Dynamic Testing of Piles, Weslie Creek Bridge, St. John's Sideroad, York Region, May 24 and June 2, 2017 Visits. Project Number: BRM-00603942-A0. June 6, 2017
Pile Logs	No official report, pile logs provided either in PDA reports or unsorted PDF files

Pile I.D.	Soil Stratum	Pile Type
WA-16 (vert.)	Cohesionless	End Bearing

Vert. Vertical Pile
EOR End of Restrike

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Distance from Bottom of Pile (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
WA-16 (vert.)	**West Abutment**	**HP310 x 110**	**15.2**	**-**	**13.4**	**16.4**	**Yes**	**-**	**263.1**	**249.7**

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
WA-16 (vert.)	**Delmag D19-32**	**"Diesel Pile Hammer"**	**1820**	**705**	**No**	**58**	**Crane**	**Fixed**	**May 24, 2017**

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
WA-16 (vert.)	**May 24, 2017**	**EOR**	**2316**	**May 24, 2017**	**EOR**	**4**	**21**	**44**	**36.2**	**-**	**-**	**1750**

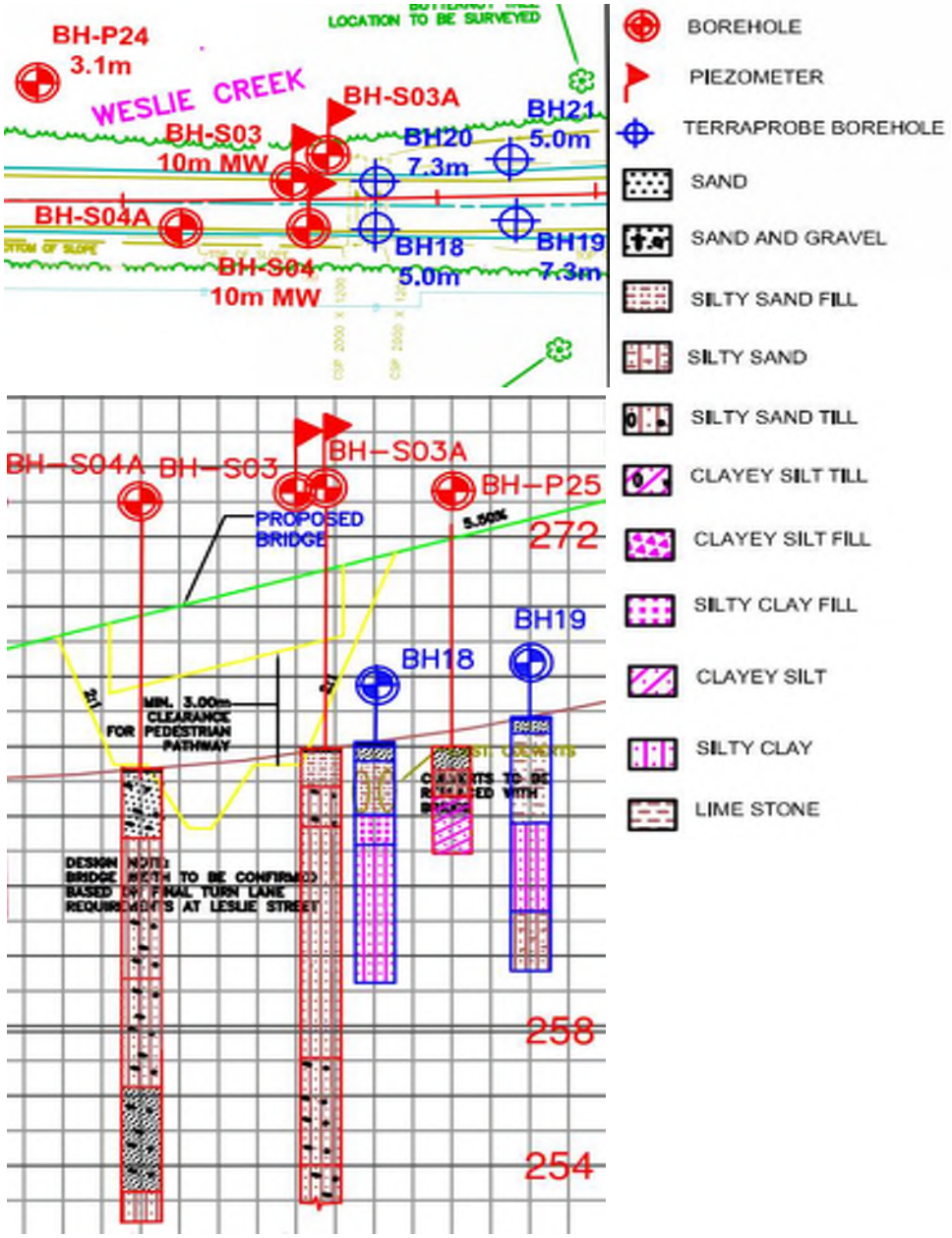
CAPWAP

Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
WA-16 (vert.)	**No CAPWAP Analysis Available for Tested Piles**							

Deep Foundation Bearing Capacity

Location	Pile Tip Elev. (m)	Bearing Capacity (kN)	
		Factored ULS	SLS
West Abutment	253	1000	800
East Abutment	254	1000	800

Soil Stratigraphy at Pile Locations

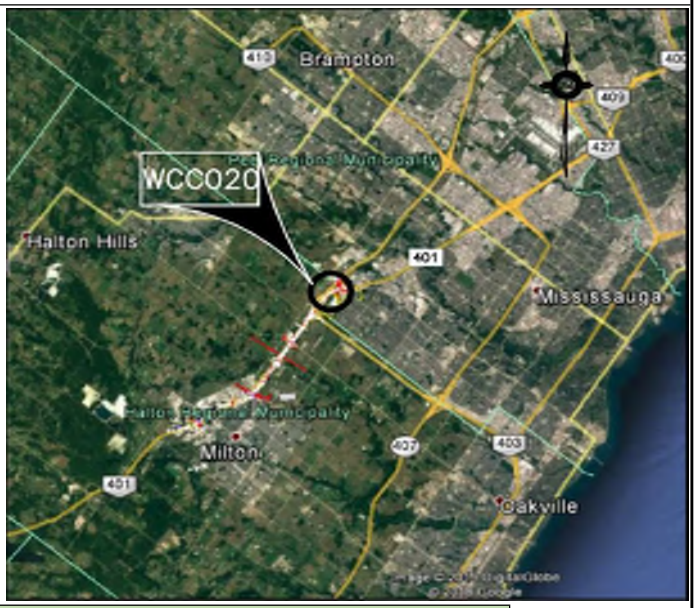


Site No:	31	Project:	H401 Expansion - CP Rail Bridge, WCC20 (24X - 0126 B1,2,3,&4)

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	EXP. Foundation and Investigation and Design Report for CPR Overhead Structure (24X-0126/B1,B2.B3&B4), Construction Document, Rev.D, H401 Expansion Project. Document Reference Number: WCC-GEO-RPT-00020, Feb. 19, 2020
Contract Dwgs	-
Pile Load Test Rpt	N.A.
PDA Report	AME. Dynamic Load Testing Summary Report for Driven HP 310 X 110 Pile Foundation- Highway 401 Expansion – CP Rail Overhead Structures- Stage 2, Structure BR-20; West Abutment. Tested Piles: WA-18, WA-28, WA-32 & WA-35 (Restrike). March 19, 2022
PDA Report	AME. Dynamic Load Testing Summary Report for Driven HP 310 X 110 Pile Foundation- Highway 401 Expansion – CP Rail Overhead Structures- Stage 2, Structure BR-20; West Abutment. Tested Piles: WA-28, WA-30, WA-31, WA32, WA-33 & WA-35 (Restrike). March 21, 2022
PDA Report	AME. Dynamic Load Testing Summary Report for Driven HP 310 X 110 Pile Foundation- Highway 401 Expansion – CP Rail Overhead Structures- Stage 2, Structure BR-20; East Abutment; Tested Piles: EA-18, EA-28 & EA-33 (Restrike). March 28, 2022
PDA Report	AME. Dynamic Load Testing Summary Report for Driven HP 310 X 110 Pile Foundation- Highway 401 Expansion – CP Rail Overhead Structures- Stage 2, Structure BR-20; East Abutment; Tested Piles: EA-18, EA-28 & EA-33 (Restrike-2). March 29, 2022
PDA Report	AME. Dynamic Load Testing Summary Report for Driven HP 310 X 110 Pile Foundation- Highway 401 Expansion – CP Rail Overhead Structures- Stage 2, Structure BR-20; East Abutment. Tested Piles: EA-14, EA-22 & EA-36 (Restrike-2). March 30, 2022
Pile Logs	No official report, only unsorted files were available.

Pile I.D.	Soil Stratum	Pile Type
WA-18	Cohesionless	End Bearing
WA-28	Cohesionless	End Bearing
WA-32	Cohesionless	End Bearing
WA-35	Cohesionless	End Bearing
WA-28	Cohesionless	End Bearing
WA-30	Cohesionless	End Bearing
WA-31	Cohesionless	End Bearing
WA-32	Cohesionless	End Bearing
WA-33	Cohesionless	End Bearing
WA-35	Cohesionless	End Bearing
EA-18	Cohesionless	End Bearing
EA-28	Cohesionless	End Bearing
EA-33	Cohesionless	End Bearing
EA-18	Cohesionless	End Bearing
EA-28	Cohesionless	End Bearing
EA-33	Cohesionless	End Bearing
EA-14	Cohesionless	End Bearing
EA-22	Cohesionless	End Bearing
EA-36	Cohesionless	End Bearing



Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Location/ Depth (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
WA-18	West Abutment	HP310 x 110	18.29	-	9.4	19.7	0.3 x 0.29 m	-	170.8	161.4
WA-28	West Abutment		18.29	-	10.45	19.7	0.3 x 0.29 m	-	170.8	160.35
WA-32	West Abutment		18.29	-	14.7	19.7	0.3 x 0.29 m	-	170.8	156.1
WA-35	West Abutment		18.29	-	12.2	19.7	0.3 x 0.29 m	-	170.8	158.6
WA-28	West Abutment		18.29	-	10.45	19.7	0.3 x 0.29 m	-	170.8	160.35
WA-30	West Abutment		18.29	-	10.75	19.7	0.3 x 0.29 m	-	170.8	160.05
WA-31	West Abutment		18.29	-	11.75	19.7	0.3 x 0.29 m	-	170.8	159.05
WA-32	West Abutment		18.29	-	14.7	19.7	0.3 x 0.29 m	-	170.8	156.1
WA-33	West Abutment		18.29	-	15.2	19.7	0.3 x 0.29 m	-	170.8	155.6
WA-35	West Abutment		18.29	-	12.2	19.7	0.3 x 0.29 m	-	170.8	158.6
EA-18	East Abutment		18.29	-	13.75	19.7	0.3 x 0.29 m	-	170.9	157.15
EA-28	East Abutment		18.29	-	13.25	19.7	0.3 x 0.29 m	-	170.9	157.65
EA-33	East Abutment		18.29	-	11.15	19.7	0.3 x 0.29 m	-	170.9	159.75
EA-18	East Abutment		18.29	-	13.75	19.7	0.3 x 0.29 m	-	170.9	157.15
EA-28	East Abutment		18.29	-	13.25	19.7	0.3 x 0.29 m	-	170.9	157.65
EA-33	East Abutment		18.29	-	11.15	19.7	0.3 x 0.29 m	-	170.9	159.75
EA-14	East Abutment		18.29	-	9.5	19.7	0.3 x 0.29 m	-	170.9	161.40
EA-22	East Abutment		18.29	-	9.25	19.7	0.3 x 0.29 m	-	170.9	161.65
EA-36	East Abutment		18.29	-	9.075	19.7	0.3 x 0.29 m	-	170.9	161.83

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
WA-18	Berminghammer B-32	"Direct drive diesel impact hammer"	3200	840	No	110	Crane	Fixed	Mar. 16, 2022
WA-28					No		Crane	Fixed	Mar. 16, 2022
WA-32					No		Crane	Fixed	Mar. 16, 2022
WA-35					No		Crane	Fixed	Mar. 16, 2022
WA-28					No		Crane	Fixed	Mar. 16, 2022
WA-30					No		Crane	Fixed	Mar. 18, 2022
WA-31					No		Crane	Fixed	Mar. 18, 2022
WA-32					No		Crane	Fixed	Mar. 16, 2022
WA-33					No		Crane	Fixed	Mar. 18, 2022
WA-35					No		Crane	Fixed	Mar. 16, 2022
EA-18					No		Crane	Fixed	Mar. 25, 2022
EA-28					No		Crane	Fixed	Mar. 25, 2022
EA-33					No		Crane	Fixed	Mar. 25, 2022
EA-18					No		Crane	Fixed	Mar. 25, 2022
EA-28					No		Crane	Fixed	Mar. 25, 2022
EA-33					No		Crane	Fixed	Mar. 25, 2022
EA-14					No		Crane	Fixed	Mar. 28, 2022
EA-22					No		Crane	Fixed	Mar. 29, 2022
EA-36					No		Crane	Fixed	Mar. 25, 2022

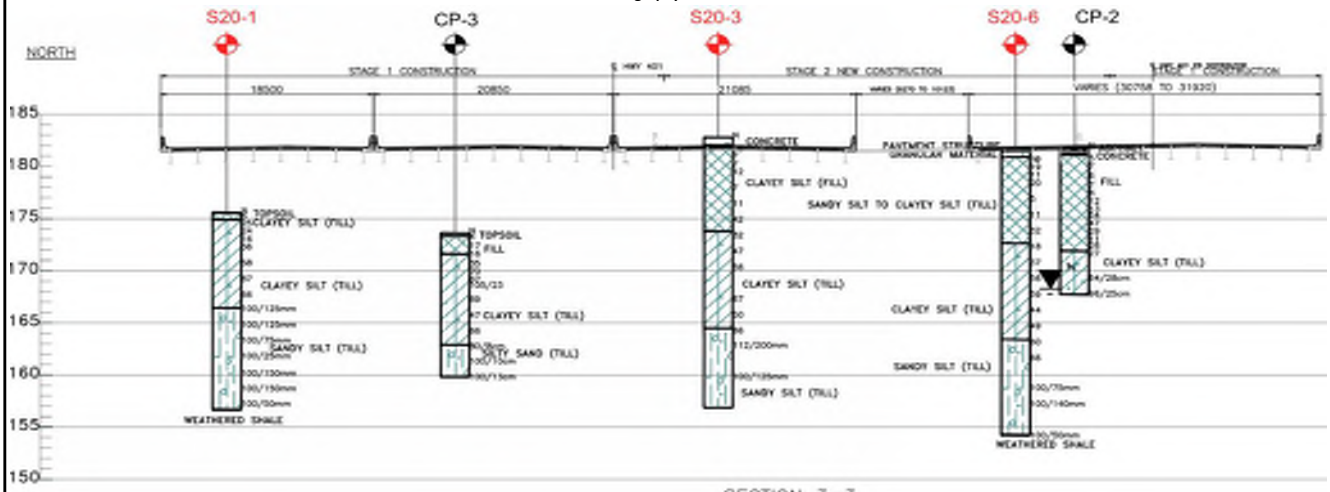
Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
WA-18	Mar. 18, 2022	Restrike	3210	Mar. 18, 2022	Restrike	-	-	-	-	3588	254.5	3211
WA-28	Mar. 18, 2022	Restrike	2382	Mar. 18, 2022	Restrike	-	-	-	-	2997	212.6	2944
WA-32	Mar. 18, 2022	Restrike	1917	Mar. 18, 2022	Restrike	-	-	-	-	3210	227.6	2645
WA-35	Mar. 18, 2022	Restrike	2637	Mar. 18, 2022	Restrike	-	-	-	-	3060	217.0	2862
WA-28	Mar. 21, 2022	Restrike 2	6902	Mar. 21, 2022	Restrike 2	-	48.9	-	44.5	3741	265.3	3210
WA-30	Mar. 21, 2022	Restrike 1	7692	Mar. 21, 2022	Restrike 1	-	47.9	-	43.5	3696	262.1	3527
WA-31	Mar. 21, 2022	Restrike 1	7535	Mar. 21, 2022	Restrike 1	-	48.7	-	44.3	3754	266.2	3550
WA-32	Mar. 21, 2022	Restrike 2	5552	Mar. 21, 2022	Restrike 2	-	37.8	-	34.4	3489	247.4	2315
WA-33	Mar. 21, 2022	Restrike 1	6421	Mar. 21, 2022	Restrike 1	-	43.9	-	39.9	3751	266.0	3430
WA-35	Mar. 21, 2022	Restrike 2	6477	Mar. 21, 2022	Restrike 2	-	45.2	-	41.1	3671	260.3	3199
EA-18	Mar. 28, 2022	Restrike	7019	Mar. 28, 2022	Restrike	-	33.8	-	30.7	3288	228.9	2877
EA-28	Mar. 28, 2022	Restrike	6700	Mar. 28, 2022	Restrike	-	27.9	-	25.4	3014	213.8	2840
EA-33	Mar. 28, 2022	Restrike	7225	Mar. 28, 2022	Restrike	-	28.4	-	25.8	3185	225.9	2871
EA-18	Mar. 29, 2022	Restrike 2	6761	Mar. 29, 2022	Restrike 2	-	39.5	-	35.9	3538	250.9	3103
EA-28	Mar. 29, 2022	Restrike 2	6353	Mar. 29, 2022	Restrike 2	-	39.7	-	36.1	3467	245.9	2965
EA-33	Mar. 29, 2022	Restrike 2	8774	Mar. 29, 2022	Restrike 2	-	33.8	-	30.7	3319	235.4	2952
EA-14	Mar. 30, 2022	Restrike	8099	Mar. 30, 2022	Restrike	-	34	-	30.9	3622	256.9	3242
EA-22	Mar. 30, 2022	Restrike	7086	Mar. 30, 2022	Restrike	-	36.2	-	32.9	3591	254.7	3178
EA-36	Mar. 30, 2022	Restrike	8189	Mar. 30, 2022	Restrike	-	33.3	-	30.3	3518	249.5	3025

CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
WA-18	Restrike	-	1061.2	33	2154.1	67	3215.3	End Bearing
WA-28	-	-	-	-	-	-	-	-
WA-32	Restrike	-	824.9	31	1819.8	69	2644.7	End Bearing
WA-35	Restrike	-	1028	34	1966	66	2994	End Bearing
WA-28	Restrike 2	-	665	21	2546	79	3211	End Bearing
WA-30	-	-	-	-	-	-	-	-
WA-31	-	-	-	-	-	-	-	-
WA-32	-	-	-	-	-	-	-	-
WA-33	-	-	-	-	-	-	-	-
WA-35	Restrike 2	-	429	13	2771	87	3200	End Bearing
EA-18								
EA-28								
EA-33								
EA-18								
EA-28								
EA-33								
EA-14								
EA-22								
EA-36								

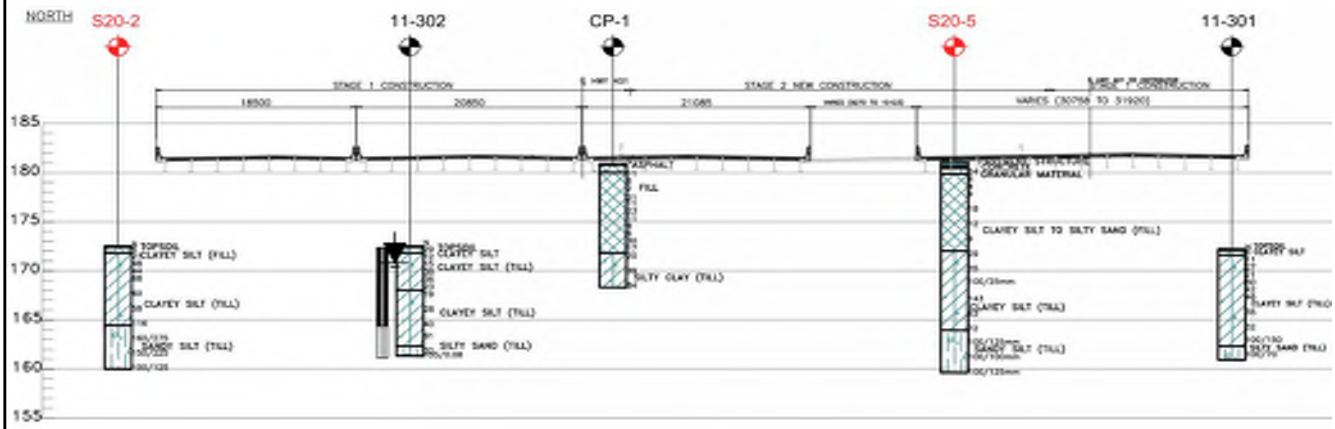
Pile Design Capacity

Foundation Unit	Relevant Borehole	Recommended level below which pile should penetrate (m)	Estimated Tip Elevation	Approximate Design Pile Length[1] (m)	Factored Axial Geotechnical Resistance at ULS (kN/pile)[2]		Factored Serviceability Axial Geotechnical Resistance (kN/pile)[2,3]		Pile Founding Stratum
					HP310x79	HP310x110	HP310x79	HP310x110	
West Abutment	CP-2, CP-3/3A, CP-4, S20-1, S20-3, S20-6	166	161	14	1300	1800	1100	1600	Very Dense Sandy Silt Till (N≥100)
East Abutment	S20-2, S20-5, 11-301, 11-302, CP-1	166	161	14	1300	1800	1100	1600	Very Dense Sandy Silt Till (N≥100)

Soil Stratigraphy at Pile Locations



SECTION 3–3
WEST ABUTMENT



SECTION 4–4
EAST ABUTMENT

Site No:	32	Project:	H401 Expansion- CN Rail Overhead Structures- Stage 2, Structure BR-03

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	EXP. Foundation and Investigation and Design Report for CN Rail Overhead Structures, Site 10X-0057/B1&B2 (WCC-03), Construction Document, Rev.D, H401 Expansion Project. Document Reference Number: WCC-GEO-RPT-00003, Feb. 19, 2020
Contract Dwgs	-
Pile Load Test Rpt	N.A.
PDA Report	AME. Dynamic Load Testing Summary Report for Driven HP 310 X 110 Pile Foundation- Highway 401 Expansion – CN Rail Overhead Structures- Stage 2, Structure BR-03; East Abutment. Tested Piles: EA-8, EA-11 & EA-15 (Restrike). April 29, 2022
PDA Report	AME. Dynamic Load Testing Summary Report for Driven HP 310 X 110 Pile Foundation- Highway 401 Expansion – CN Rail Overhead Structures- Stage 2, Structure BR-03; West Abutment. Tested Piles: WA-7A, WA-11 & WA-15 (Restrike). May 27, 2022
PDA Report	AME. Dynamic Load Testing Summary Report for Driven HP 310 X 110 Pile Foundation- Highway 401 Expansion – CN Rail Overhead Structures- Stage 2, Structure BR-03; West Abutment. Tested Piles: WA-10 & WA-14 (Restrike). June 6, 2022
Pile Logs	No official report, only unsorted files were available.

Pile I.D.	Soil Stratum	Pile Type
EA-8	Layered/Cohesionless	Friction/End Bearing
EA-11	Cohesive	Friction
EA-15	Layered/Cohesionless	Friction/End Bearing
WA-7A	Cohesive	Friction
WA-11	Cohesive	Friction
WA-15	Cohesive	Friction
WA-10	Cohesive	Friction
WA-14	Cohesive	Friction

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Location/ Depth (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
EA-8	East Abut. (Stage 2)	310 x 110	33.6	-	28.65	36.3	0.3 x 0.29 m	21.4	214.5	185.97
EA-11	East Abut. (Stage 2)		33.6	-	21.9	36.3	0.3 x 0.29 m	21.4	214.5	192.78
EA-15	East Abut. (Stage 2)		33.6	-	27.55	36.3	0.3 x 0.29 m	21.4	214.5	187.12
WA-7A	West Abut. (Stage 2)		18.29	-	15.1	19.7	0.3 x 0.29 m	-	214.33	199.23
WA-11	West Abut. (Stage 2)		18.29	-	17.4	19.7	0.3 x 0.29 m	-	214.33	196.93
WA-15	West Abut. (Stage 2)		18.29	-	14.5	19.7	0.3 x 0.29 m	-	214.33	199.83
WA-10	West Abut. (Stage 2)		23.68	-	22	25.6	0.3 x 0.29 m	18.29	214.33	192.33
WA-14	West Abut. (Stage 2)		21.67	-	20.9	23.4	0.3 x 0.29 m	18.29	214.33	193.43

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
EA-8	Berminghammer B-5505	Diesel	4200	840	No	114	Crane	Fixed	Apr. 28, 2022
EA-11					No				Apr. 28, 2022
EA-15					No				Apr. 28, 2022
WA-7A					No				May 26, 2022
WA-11					No				May 26, 2022
WA-15					No				May 26, 2022
WA-10					No				June 3, 2022
WA-14					No				June 3, 2022

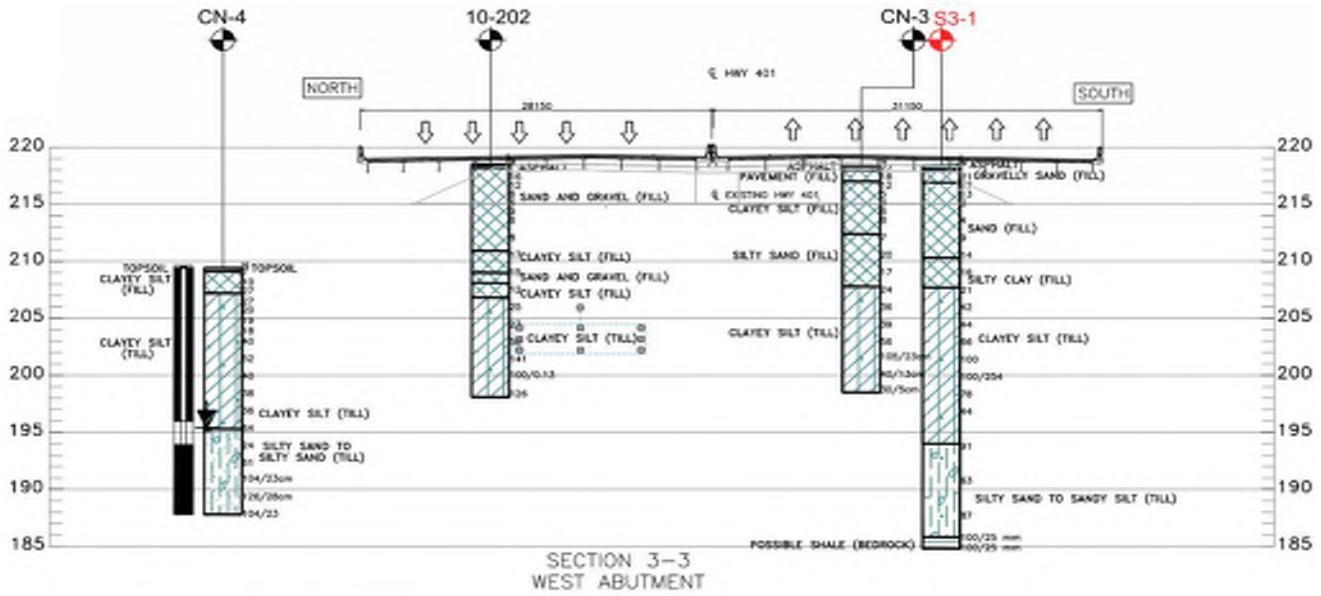
Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
EA-8	Apr. 29, 2022	Restrike	7845	Apr. 29, 2022	Restrike	-	48.9	-	43	3103	220.1	2409
EA-11	Apr. 29, 2022	Restrike	6344	Apr. 29, 2022	Restrike	-	42.7	-	37	3118	221.1	2493
EA-15	Apr. 29, 2022	Restrike	5700	Apr. 29, 2022	Restrike	-	45.2	-	40	3191	214.1	2728
WA-7A	May 27, 2022	Restrike	5584	May 27, 2022	Restrike	-	48.3	-	42	3346	237.3	2169
WA-11	May 27, 2022	Restrike	8376	May 27, 2022	Restrike	-	46.3	-	41	3302	234.2	2323
WA-15	May 27, 2022	Restrike	5436	May 27, 2022	Restrike	-	50.9	-	45	3454	245.0	2459
WA-10	June 6, 2022	Restrike	5463	June 6, 2022	Restrike	-	61.3	-	53.3	3453	244.9	2684
WA-14	June 6, 2022	Restrike	6051	June 6, 2022	Restrike	-	48.4	-	41.7	3262	231.4	2494

CAPWAP								
Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
EA-8								
EA-11	Restrike	-	1877	75	617	25	2494	Friction
EA-15								
WA-7A	-	-	-	-	-	-	-	-
WA-11	-	-	-	-	-	-	-	-
WA-15	Restrike	-	1636	67	823	33	2459	Friction
WA-10	-	-	-	-	-	-	-	-
WA-14	Restrike	-	1645	66	849	34	2494	Friction

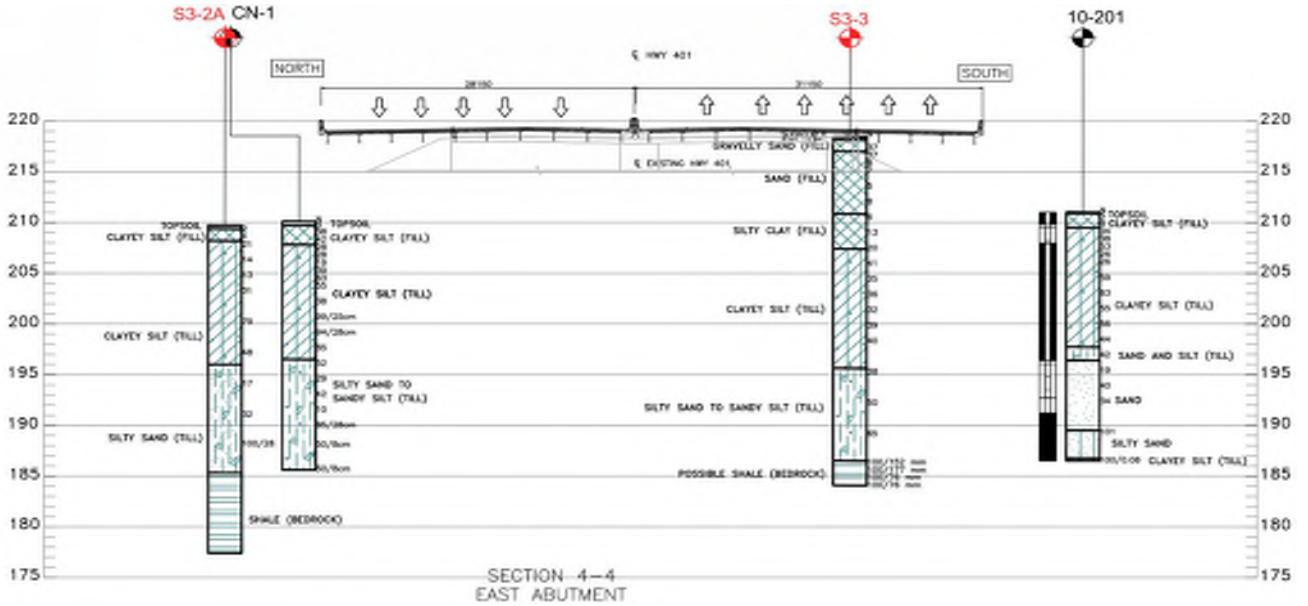
Pile Design Capacity

Foundation Unit	Relevant Borehole	Recommended level below which pile should penetrate (m)	Estimated Tip Elevation	Approximate Design Pile Length[1] (m)	Factored Axial Geotechnical Resistance at ULS (kN/pile)[1]		Factored Serviceability Axial Geotechnical Resistance (kN/pile)[2,3]		Pile Founding Stratum
					HP310x79	HP310x110	HP310x79	HP310x110	
West Abutment and pier	S3-1, 10-202, CN-3, CN-4	203	200 (WBL) 202 (EBL)	12.5 to 14.5	1000	1400	825	1200	V. stiff to hard clayey silt till
		191	189 (WBL) 185 (EBL)	25.5 to 29.5	1300	1800	1100	1600	Very Dense Sandy Silt Till (N≥100)/ Shale bedrock
East Abutment and Pier	S3-2A,S3-3, 10-201, CN-1 and CN-2	190.0	185.5(WBL) 185.0(EBL)	29 to 29.5	1300	1800	1100	1600	Very Dense Silty Sand to Sandy Silt Till (N≥100)/ Shale Bedrock

Soil Stratigraphy at Pile Locations



SECTION 3–3
WEST ABUTMENT



SECTION 4–4
EAST ABUTMENT

Site No:	33	Project:	H401 Expansion - Credit River Bridge Structures, WCC22

Pile Load Test	No
PDA Test	Yes
Hiley Test	Yes

Document Type	Document Title
FIDR	EXP. Foundation and Investigation and Design Report for Credit River Bridge. Site 24X-0128/B1,B2.B3&B4 (WCC-22), Construction Document, Rev.2, H401 Expansion Project. Document Reference Number: WCC-GEO-RPT-00022, Feb. 15, 2021
Contract Dwgs	-
Pile Load Test Rpt	N.A.
PDA Report	AME. Dynamic Load Testing Summary Report for Driven HP 310 X 110 Pile Foundation- Highway 401 Expansion – Credit River Bridge Structures- Stage 2, Structure BR-22; East Abutment. Tested Piles: EA-20, EA-35 & EA-42 (Restrike). April 6, 2022
PDA Report	AME. Dynamic Load Testing Summary Report for Driven HP 310 X 110 Pile Foundation- Highway 401 Expansion – Credit River Bridge Structures- Stage 2, Structure BR-22; West Abutment. Tested Piles: WA-15, WA-24 & WA-38 (Restrike). April 13, 2022
Pile Logs	No official report, only unsorted files were available.

Pile I.D.	Soil Stratum	Pile Type
EA-20	Shale Bedrock	End Bearing
EA-35	Shale Bedrock	End Bearing
EA-42	Shale Bedrock	End Bearing
WA-15	Shale Bedrock	End Bearing
WA-24	Shale Bedrock	End Bearing
WA-38	Shale Bedrock	End Bearing

Pile Information

Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/ Bearing Point	Splice Location/ Depth (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
EA-20	East Abut. (Stg 2)	HP310 x 110	9.18	-	6.25	9.9	0.3 x 0.29 m	-	162.0	155.75
EA-35	East Abut. (Stg 2)	HP310 x 110	9.18	-	5.85	9.9	0.3 x 0.29 m	-	162.0	156.15
EA-42	East Abut. (Stg 2)	HP310 x 110	9.18	-	5.4	9.9	0.3 x 0.29 m	-	162.0	156.6
WA-15	West Abut. (Stg 2)	HP310 x 110	9.18	-	5.6	9.9	0.3 x 0.29 m	-	163.7	158.1
WA-24	West Abut. (Stg 2)	HP310 x 110	9.21	-	5.7	9.9	0.3 x 0.29 m	-	163.7	158
WA-38	West Abut. (Stg 2)	HP310 x 110	9.22	-	6.2	9.9	0.3 x 0.29 m	-	163.7	157.5

Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
EA-20	Berminghammer B-32	"Direct drive diesel impact hammer"	3200	840	No	110	Crane	Fixed	Apr. 5, 2022
EA-35					No				Apr. 5, 2022
EA-42					No				Apr. 5, 2022
WA-15					No	87			Apr. 12, 2022
WA-24					No				Apr. 12, 2022
WA-38					No				Apr. 12, 2022

Pile No.	Hiley Test Results			Pile Driving Analyzer Data								
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/ mm)	EMX (kJ)	Speed (bpm)	ETR (%)	FMX (kN)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
EA-20	Apr. 6, 2022	Restrike	5779	Apr. 6, 2022	Restrike	-	26.7	-	24.3	2942	208.7	2775
EA-35	Apr. 6, 2022	Restrike	6106	Apr. 6, 2022	Restrike	-	21.6	-	19.6	2751	195.1	2469
EA-42	Apr. 6, 2022	Restrike	4315	Apr. 6, 2022	Restrike	-	25.8	-	23.5	3019	214.1	2302
WA-15	Apr. 13, 2022	Restrike	5598	Apr. 13 2022	Restrike	-	27.8	-	32.0	3093	219.3	2330
WA-24	Apr. 13, 2022	Restrike	6374	Apr. 13 2022	Restrike	-	28	-	32.2	4190	297.2	3608
WA-38	Apr. 13, 2022	Restrike	8700	Apr. 13 2022	Restrike	-	29.6	-	34.0	4038	286.4	3391

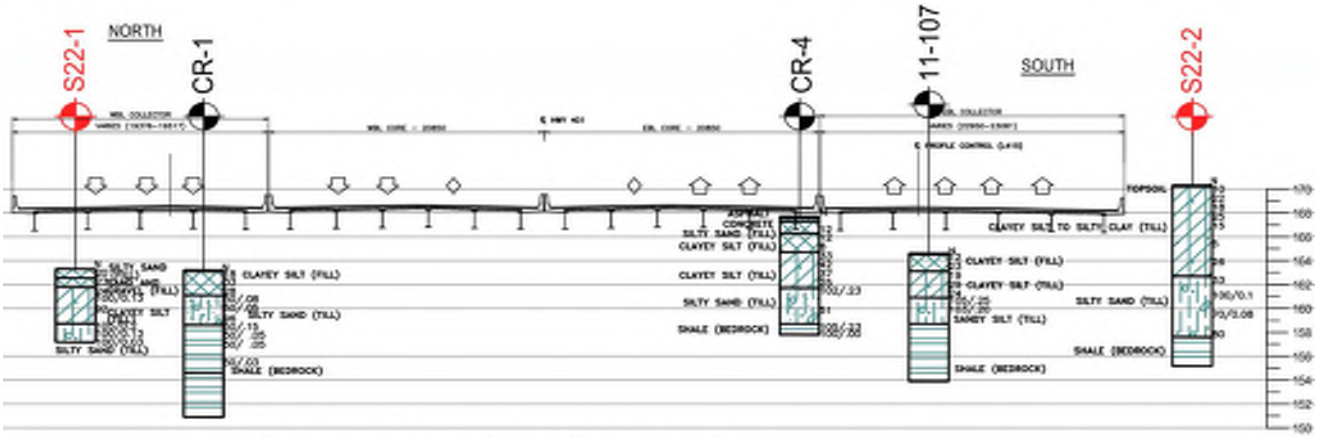
CAPWAP

Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
EA-20	-	-	-	-	-	-	-	-
EA-35	-	-	-	-	-	-	-	-
EA-42	Restrike	-	703	31	1599	69	2302	End Bearing
WA-15	Restrike	-	585	25	1745	75	2330	End Bearing
WA-24	-	-	-	-	-	-	-	-
WA-38	-	-	-	-	-	-	-	-

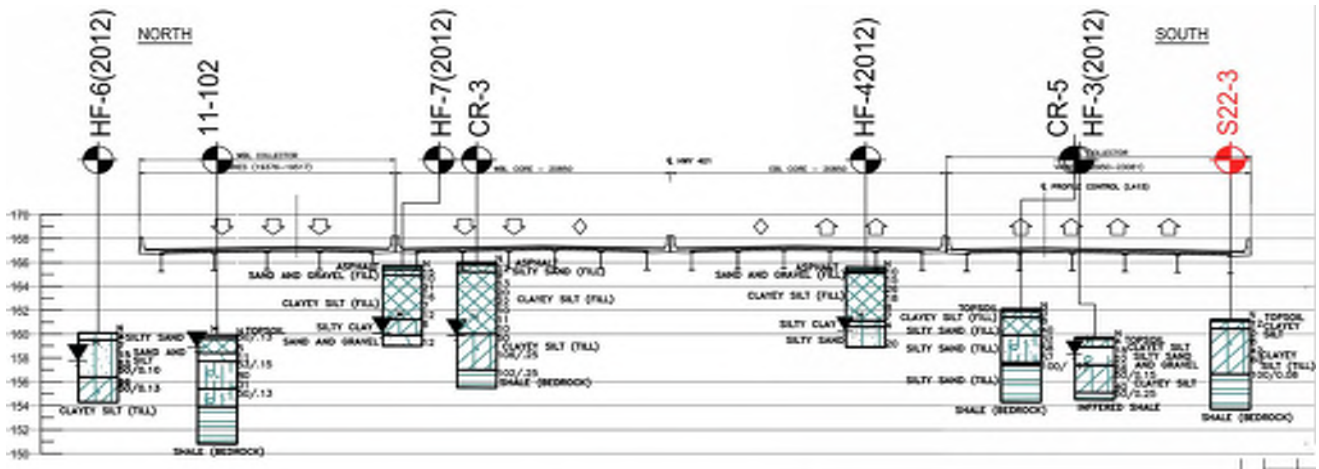
Pile Design Capacity

Foundation Unit	Relevant Borehole	Recommended level below which pile should penetrate (m)	Estimated Tip Elevation	Approximate Design Pile Length[1] (m)	Factored Axial Geotechnical Resistance at ULS (kN/pile)[2]		Factored Serviceability Axial Geotechnical Resistance (kN/pile)[2,3]		Pile Founding Stratum
					HP310x79	HP310x110	HP310x79	HP310x110	
West Abutment	S22-1, S22-2, CR-1, 11-107	158	157	~7.28	1150	1600	950	1400	Shale Bedrock
East Abutment	S22-3, 11-102, 11-103, CR-3, CR-5	158	155.5(WBL) 157.0 (EBL)	~5.72 (EBL) to 7.22 (WBL)	1150	1600	950	1400	Shale Bedrock

Soil Stratigraphy at Pile Locations



SECTION 3–3 C/L WEST ABUTMENT



SECTION 6–6 C/L EAST ABUTMENT

Site No:	34	Project:	CNR/CPR Structures - Northwest Metro Arterial	Pile Load Test	Yes
				PDA Test	Yes
				Hiley Test	Yes

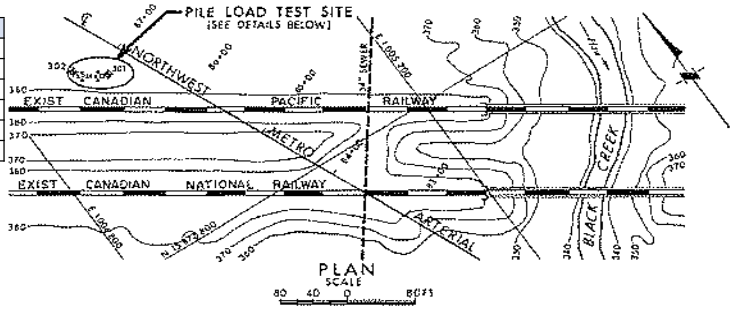
Document Type	Document Title
FIDR	N/A
Contract Dwgs	N/A
Pile Load Test Report	Engineering Materials Office. Pavement & Foundation Design Office. Evaluation of Selected Piles Under Axial and Lateral Loading Conditions, C.N.R./C.P.R. Structures, Northwest Metro Arterial. W.P. 33-76-13&14, Dist. 6, Cont. 80-70, Str. Site 37-1079. Feb. 1983
PDA Report	N/A
Pile Logs	N/A

Purpose: Evaluate the comparative performance of various piles and confirm the pile capacities in complex soil strata

Test Method: ASTM D1143-74 Standard Loading Procedure, Piles were planned to be loaded to failure. Increments of 25% of design load

Pile I.D.	Date	Failure Criterion				Reason for Test Termination
		MTC	Davisson	Flaate	CFM	
Pile 1	Jul. 10, 1979	1557	1468	1557	1557	Excessive movement (plunging failure)
Pile 4	Jul. 9, 1979	1423	1334	1512	1468	Excessive movement (plunging failure)
Pile 5	Jul. 3, 1979	2713	2802	2802	2847	Excessive movement (plunging failure)
Pile 6	Jul. 4, 1979	2402	2269	2269	2358	Excessive movement (plunging failure)
Pile 7	Jul. 5, 1979	712	667	712	712	Excessive movement (plunging failure)
Pile 10	Jul. 6, 1979	1779	1735	1824	1913	Excessive movement (plunging failure)

Pile I.D.	Soil Stratum	Pile Type
Pile 1	Cohesionless	Friction
Pile 4	Cohesionless	Friction/End Bearing
Pile 5	Layered/Cohesionless	Friction/End Bearing
Pile 6	Layered	Friction
Pile 7	Cohesionless	End
Pile 10	Layered/Cohesionless	Friction/End Bearing



Vert. Piles installed vertically

EOID End of Initial Drive

Pile Information										
Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/Bearing Point	Splice Location/ Depth (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (m)
Pile 1 (vert.)	~180 m West of Black Creek, North Side of Tracks	HP12 x 74	18.3	-	14.8	19.7	Yes	yes (assumed)	114	99.0
Pile 4 (vert.)		324OD6.4WT Pipe	15.9	-	14.7	7.8	Yes	Yes	114	99.2
Pile 5 (vert.)		HP12 x 74	30.5	-	27.6	32.9	Yes	yes	114	86.3
Pile 6 (vert.)		324OD6.4WT Pipe	32.1	-	27.4	15.8	Yes	yes	114	86.5
Pile 7 (vert.)		Timber Pile, 14"butt,9" tip	13.5	-	12.7	1.2 - 2.5	No	no	114	101.2
Pile 10 (vert.)		precast rein conc 12x12	15.2	-	14.6	33.2	No	7.6	114	99.2

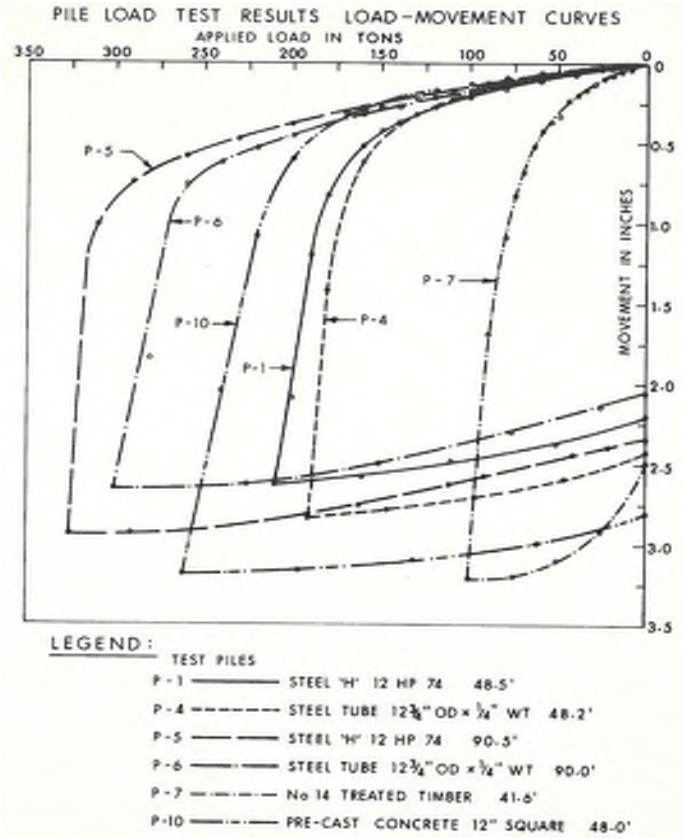
Hammer Specification							Pile Driving Details		
Pile No.	Hammer Specification	Hammer System Type (Hydraulic, Diesel, Drop)	Weight of Ram/ Piston (kg)	Weight of Anvil (kg)	Cushion	Hammer Energy (kJ)	Pile Driving Equipment (Crane, etc.)	Pile Driving Lead (Fixed vs. Swinging)	Pile Installation Date
Pile 1	Berminghammer B400	Diesel	1524	425	Yes	62.4	Crane*	Fixed*	Jun. 25, 1979
Pile 4	Berminghammer B400	Diesel	1524	425	Yes	62.4			Jun. 22, 1979
Pile 5	Berminghammer B400	Diesel	1524	425	Yes	62.4			Jun. 22, 1979
Pile 6	Berminghammer B400	Diesel	1524	425	Yes	62.4			Jun. 21, 1979
Pile 7	Berminghammer B225	Diesel	914	335	Yes	39.3			Jun. 25, 1979
Pile 10	Berminghammer B400	Diesel	1524	425	Yes	62.4			Jun. 22, 1979

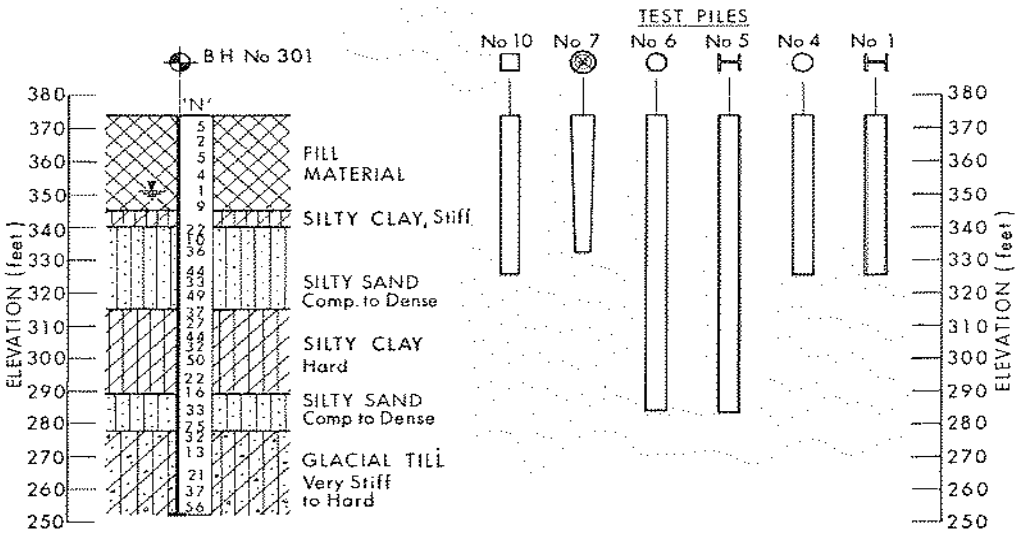
*Note: Pile driving equipment and lead assumed based on hammer type used to perform Hiley/PDA test.

Pile No.	Hiley Test Results			Pile Driving Analyzer Data							
	Date	Event	Ultimate Compression Resistance (kN)	Date	Event	Equivalent Pres. (Blows/25mm) or (Blows/mm)	EMX (kJ)	Speed (bpm)	ETR (%)	CSX (Mpa)	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)
Pile 1	Jun. 25, 1979	EOID	1290	Jun. 25, 1979	EOID	-	17.8	-	28.47826087	134.4	1157
Pile 4	Jun. 22, 1979	EOID	1512	Jun. 22, 1979	EOID	-	30.1	-	48.26086957	264.1	1601
Pile 5	Jun. 22, 1979	EOID	1957	Jun. 22, 1979	EOID	-	23.9	-	38.26086957	203.4	2891
Pile 6	Jun. 21, 1979	EOID	1334	Jun. 21, 1979	EOID	-	33.1	-	53.04347826	288.2	2580
Pile 7	Jun. 25, 1979	EOID	756	Jun. 25, 1979	EOID	-	13.4	-	34.13793103	9.5	623
Pile 10	Jun. 22, 1979	EOID	1601	Jun. 22, 1979	EOID	-	14.9	-	23.91304348	25.6	1512

CAPWAP

Pile No.	Event	Equivalent Pres. blows/mm)	Shaft Capacity (kN)	Shaft %	Toe Capacity (kN)	Toe %	Evaluated Ultimate Mobilised Geotechnical Resistance (kN)	Pile Type
Pile 1	EOID	-	1023.1	88	133.4	12	1157	Friction
Pile 4	EOID	-	667.2	42	934.1	58	1601	End Bearing
Pile 5	EOID	-	1645.8	57	1245.5	43	2891	Friction
Pile 6	EOID	-	2357.5	91	222.4	9	2580	Friction
Pile 7	EOID	-	266.9	43	355.9	57	623	End Bearing
Pile 10	EOID	-	800.7	53	711.7	47	1512	Friction





SOIL STRATIGRAPHY AND TEST PILE EMBEDMENT ELEVATIONS