



MTO Agreement: 5018-E-0012

ASSIGNMENT #15

Controlling the Installation of Driven Piles
Final Presentation

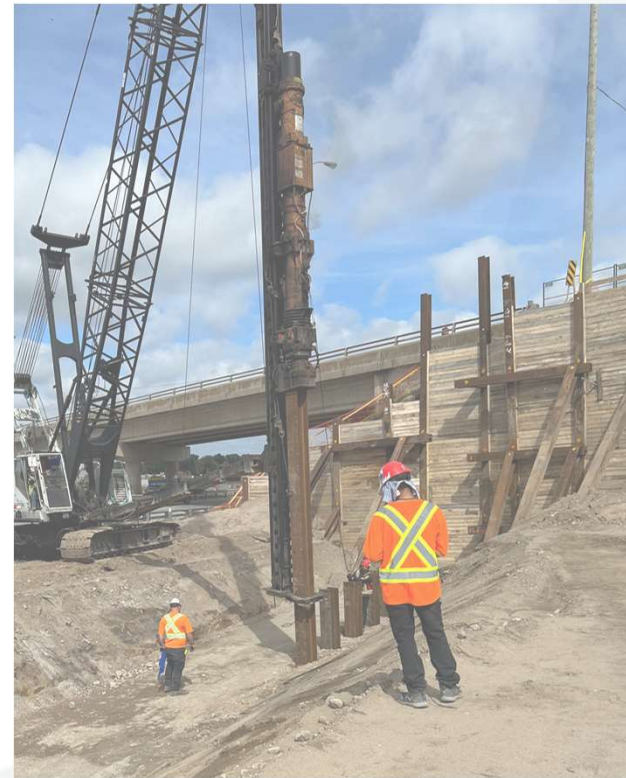
May 2023

Acknowledgment

EXP wishes to acknowledge the invaluable support and contribution of MTO Foundations, Tony Sangiuliano, P.Eng. (Head) and Brady Lin, P.Eng. in initiating the study, providing the MTO data base, and important critical feedback in the development and production of the reports and the policy.

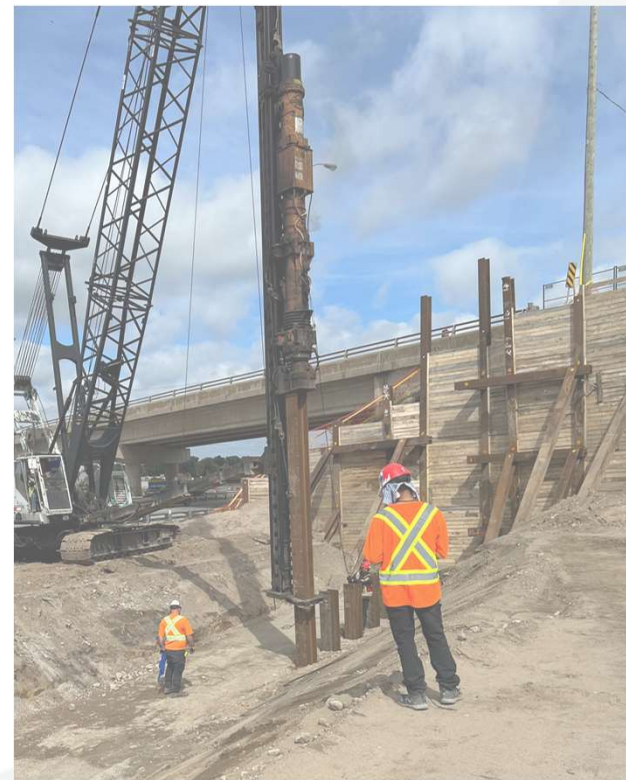
Agenda

- 01 Introduction
- 02 Motivation and Objectives
- 03 Methodology
- 04 Data Collection and Analysis
- 05 Summary of Results
- 06 Conclusions and Recommendations



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Introduction

- 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's goal to maintain and develop expertise is evidenced by the commissioning of this study.
- EXP was retained by the Ministry of Transport Ontario (MTO) to provide a comparison of the estimated developed pile capacity generated by the Ministry's Modified Hiley Formula versus those obtained by the Pile Driving Analyzer (PDA) in various conditions and time.
- MTO intent was to explore the need for changes to the current strategy for monitoring piling installations on MTO projects.



www.ontario.ca

Introduction

Hiley Testing vs. PDA Testing

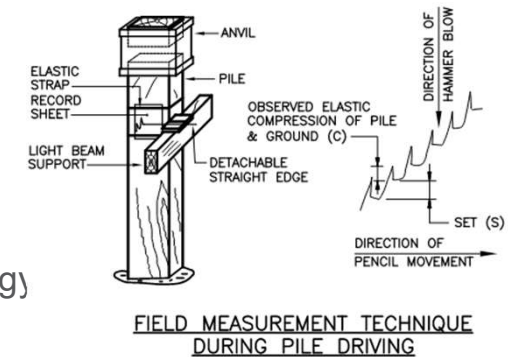
Hiley Formula: The Hiley formula is regarded as one of the simplest dynamic formulas to monitor pile capacity. A modified version is currently used as a default tool on MTO projects.

Advantages:

- Easy to be used and low cost.
- Evaluates static soil resistance.
- It considers pile driver efficiency, pile weight, pile length, and the loss of transmitted energy caused by pile cap, pile, and soil compression.

Disadvantages:

- It is assumed that the pile behaves like a rigid rod and that the compression it experiences during striking is uniform across the length of the pile.
- The formula consists of many coefficients (e.g., e_f , n , e , C), which were developed on correlation from recorded field observations (not measurements).
- It does not consider the actual energy transferred to the pile.



Introduction

Hiley Testing vs. PDA Testing

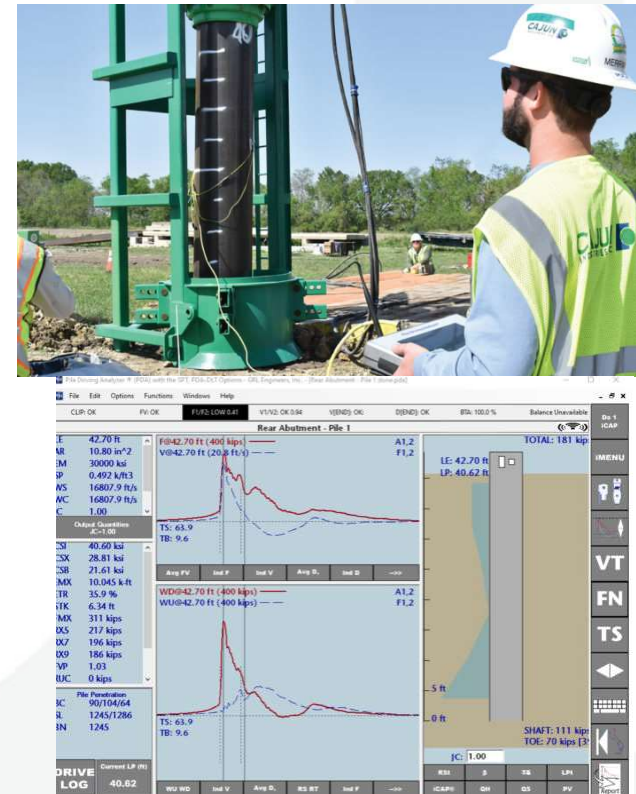
PDA: The Pile Driving Analyzer has evolved to be the most widely employed system for Dynamic load testing and pile driving monitoring.

Advantages:

- PDA test is a relatively low-cost testing method compared to static load tests.
- Provides a range of data on pile behavior, including pile capacity, hammer performance, pile integrity, and driving stresses,.....etc.
- Assesses the nominal resistance versus pile penetration depth.
- Evaluates the nominal resistance at time of testing; allows for checking 'set-up' or 'relaxation'.
- It is an accurate testing method, with results that can be used to predict the behavior of the pile under different loading conditions.

Disadvantage:

- It requires experienced personnel.



www.pile.com



Introduction

Pile Driving Control in Canadian Jurisdictions

- Across Canada, Canadian provinces adopt different techniques to monitor piles during and after driving.
- The Ministry of Transportation of Ontario currently uses the modified Hiley Formula coupled with some levels of dynamic monitoring. The modified Hiley formula is used as a pile driving control tool (i.e., as a monitoring tool, not a design tool). The policy is focused on frictional piles in cohesionless soils.
- Most of the other provinces (i.e., Alberta, British Columbia, New Brunswick and Newfoundland and Labrador) are primarily utilize dynamic monitoring (PDA) for piles.



www.open.lib.umn.edu

Agenda

01

Introduction

02

Motivation and Objectives

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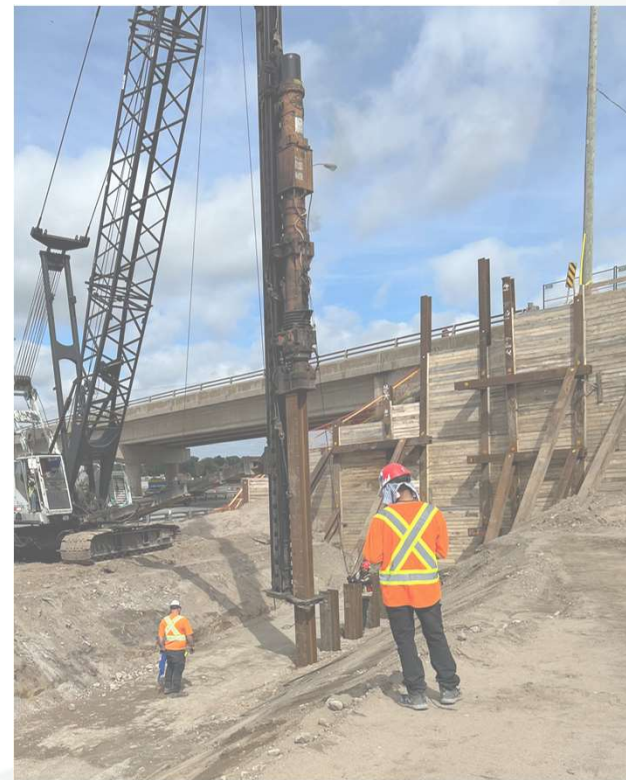
Data Collection and Analysis

05

Summary of Results

06

Conclusions and Recommendations



Motivation and Objectives

Motivations

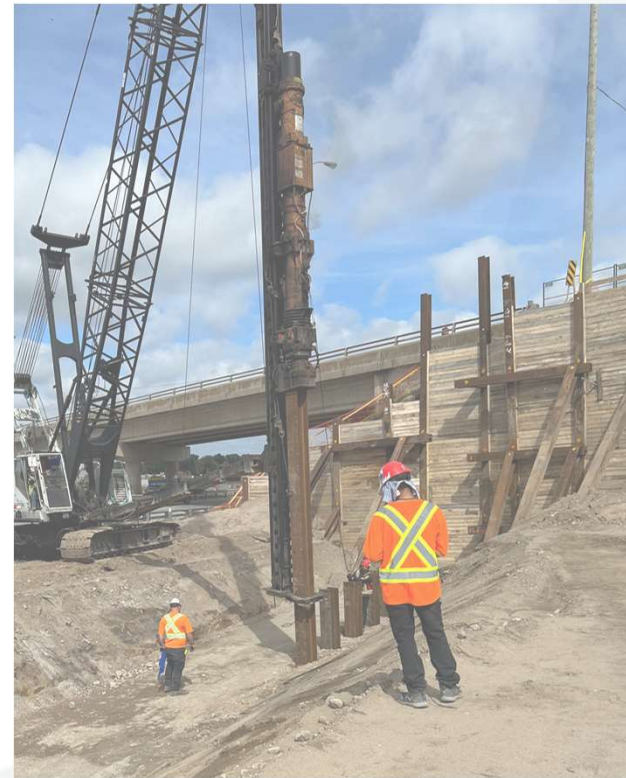
- MTO's priorities to update its technical standards, noting also the progression to LRFD.
- The inconsistency of results produced due to the application of the MTO's Modified Hiley Formula from both pile to pile and site to site has led to discussions regarding the validity of applying the formula on MTO projects.
- 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.

Objective

- 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.

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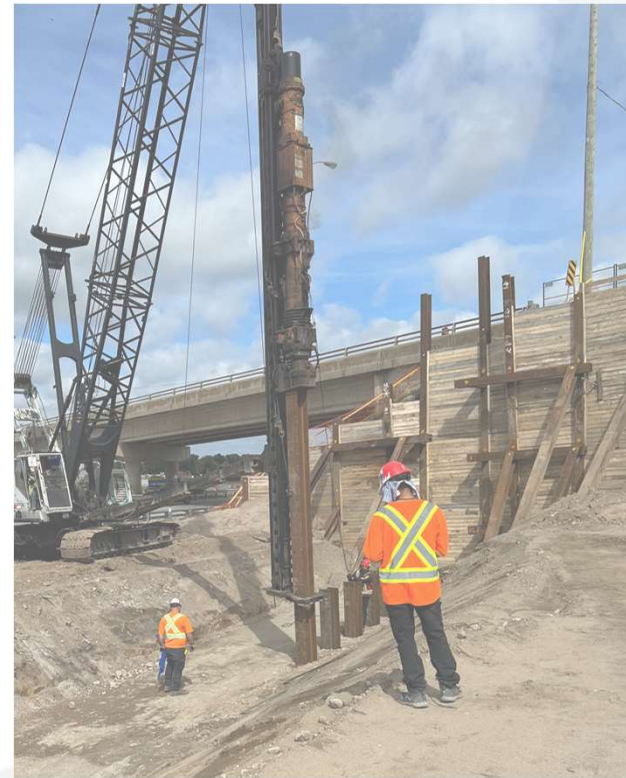


Methodology



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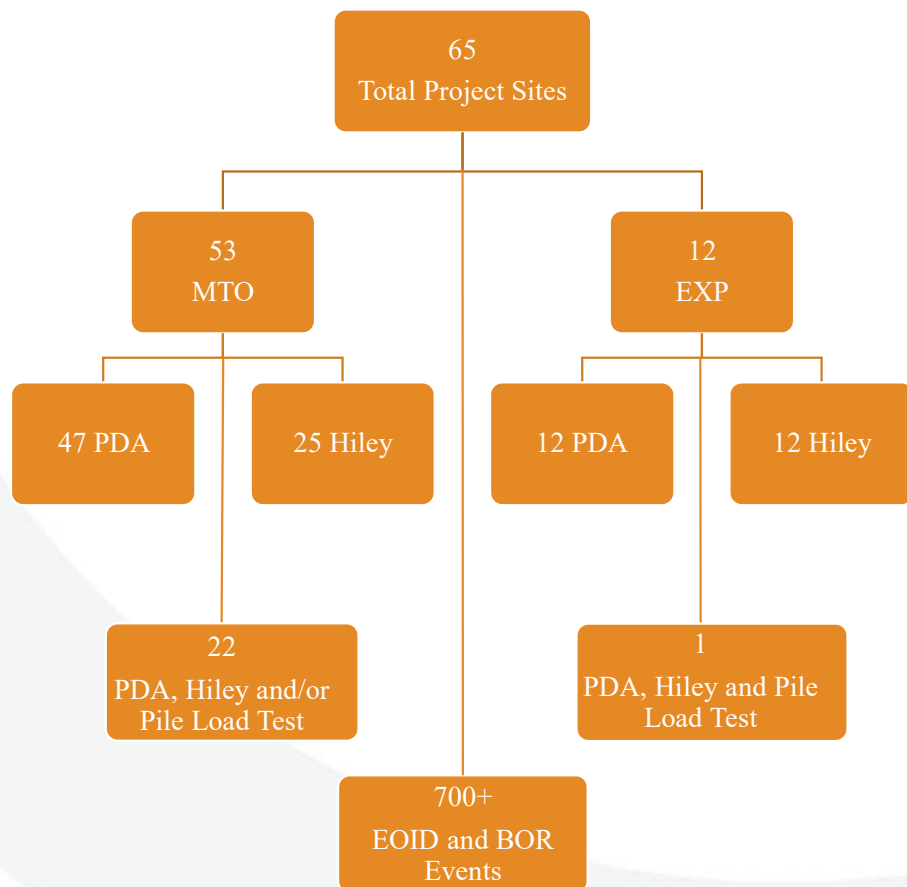


Data Analysis and Results

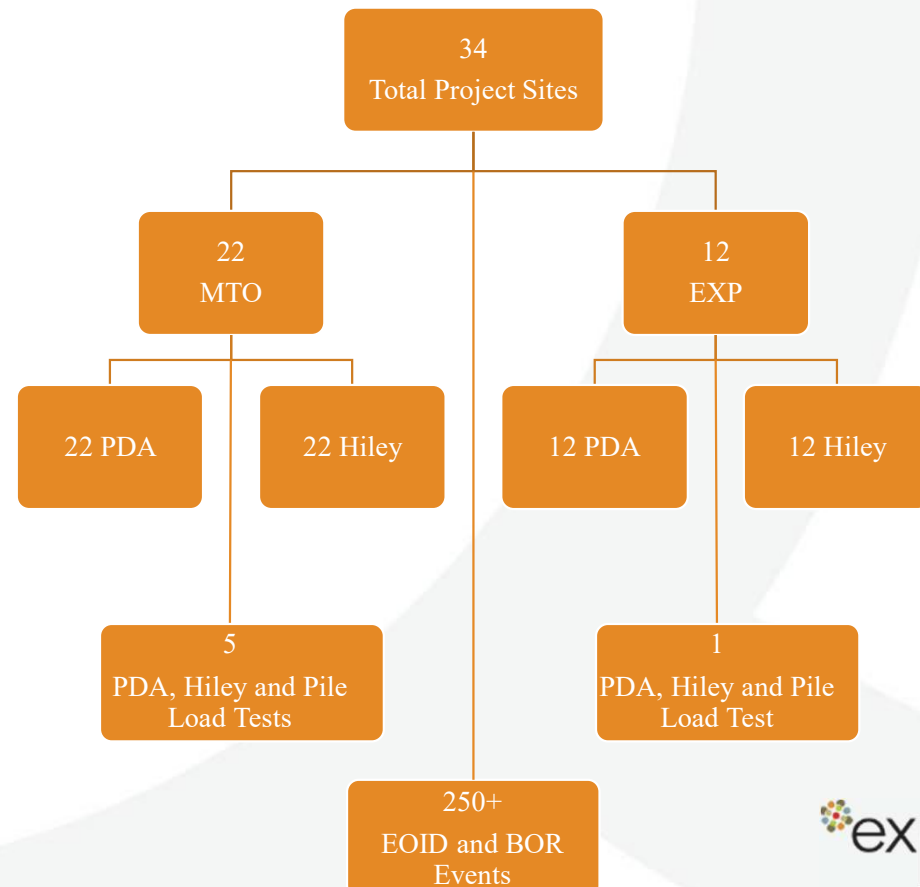
Data Collection

Data Collection and Analysis

Total Available Site Data



Total Available Complete Site Data



Project Overview: Data Compilation

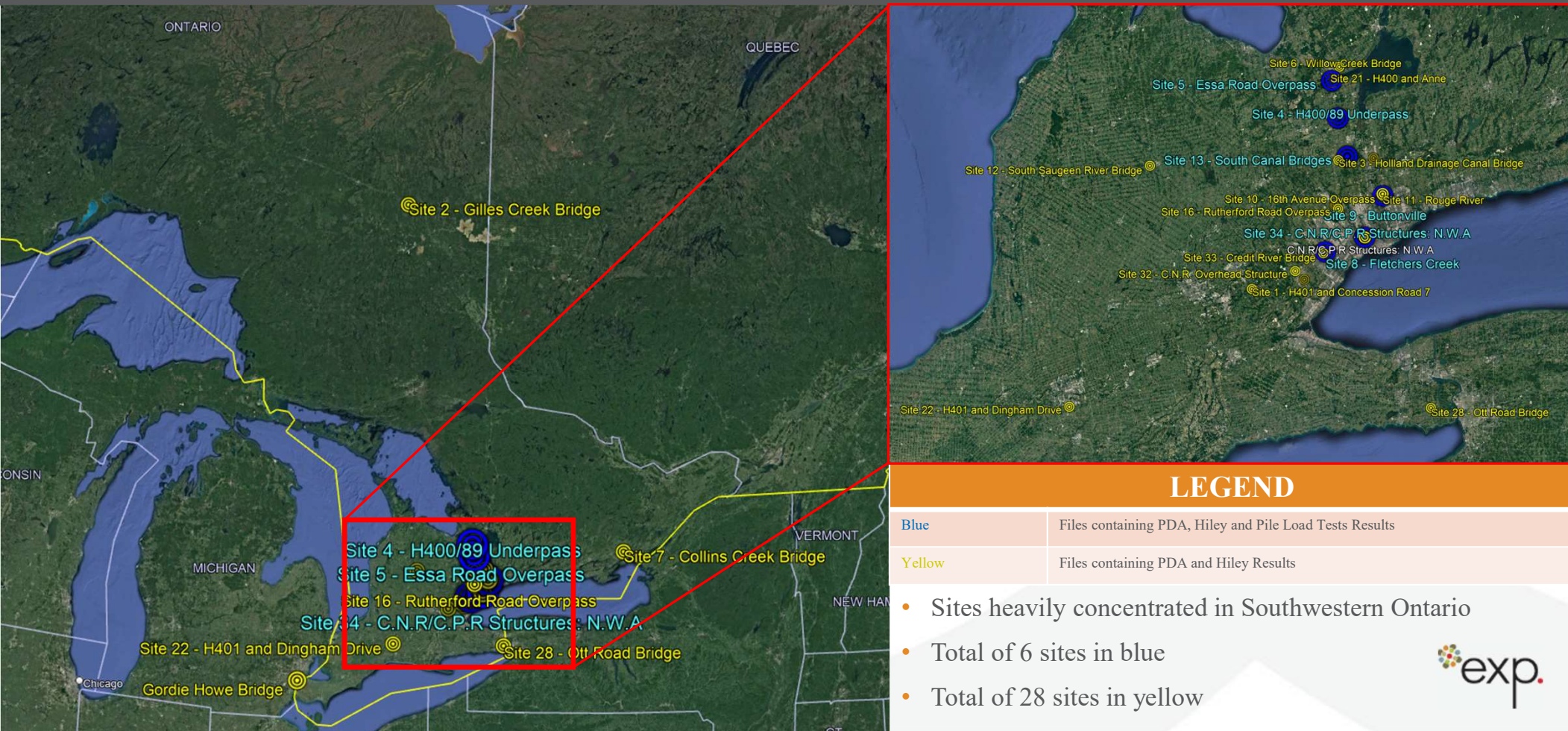
Hiley and/or PDA Data not Available

Site No.	Project Name	Hiley Data	PDA Data
1	Hwy 401 Franklin Road Underpass	No*	Yes
2	Kishkaesi River Bridge	No	Yes
3	Hwy 400 South Canal Bridges	No*	Yes
4	Hwy 417 Ramsayville	No	Yes
5	Hwy 569 Blanche River Bridge Replacement	No*	Yes
6	Zenway Blvd Underpass	No*	Yes
7	Langstaff Road over Rainbow Creek	Yes	No
8	B14A-Hwy 427 NBL over Street A	Yes	No
9	B14B-Hwy 427 SBL over Street A	Yes	No
10	M12	No	Yes
11	M13	No	Yes
12	M16	No	Yes
13	M17	No	Yes
14	M19	No	Yes
15	M37	No	Yes
16	M39	No	No
17	M43	No	Yes
18	M45	No	Yes
19	M59	No	Yes
20	W5	No	Yes
21	W6	No	No
22	W10	No	Yes
23	W11	No	Yes
24	W12	No	Yes
25	W13	No	Yes
26	W16	No	No
27	W18	No	Yes
28	W19	No	Yes
29	W21	No	Yes
30	W22	No	Yes
31	W30	No	Yes

Both Hiley and PDA Data Available

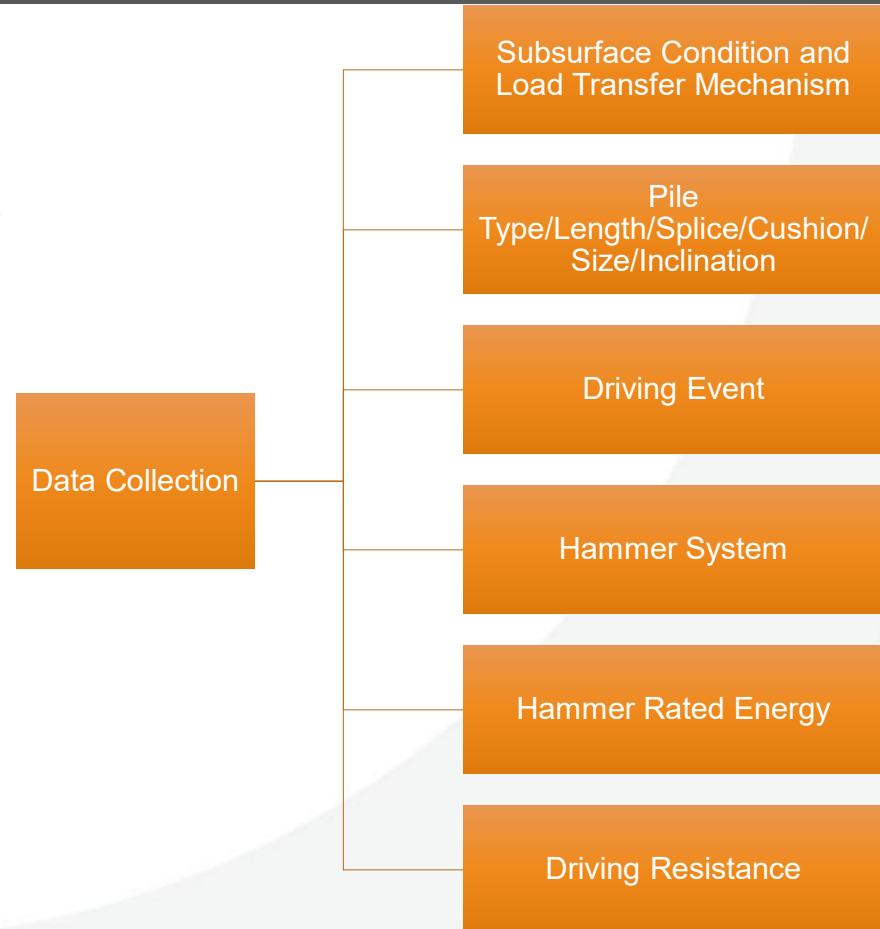
Site No.	Project Name	Hiley Data	PDA Data
1	Hwy 6/401-New Concession Rd Underpass	Yes	Yes
2	Hwy 579-Gilles Creek Bridge Replacement	Yes	Yes
3	Hwy 9 Holland Drainage Canal Bridge Replacement	Yes	Yes
4	Highway 400 & 89 Interchange	Yes	Yes
5	Hwy 400 and Essa Rd. Overpass Replacement	Yes	Yes
6	400/Willow Creek Bridge Replacement	Yes	Yes
7	401/Collins Creek WBL Bridge Replacement	Yes	Yes
8	Hwy 401 Fletchers Creek Culvert Replacement	Yes	Yes
9	Hwy 404 & 16th Avenue (Buttonville)	Yes	Yes
10	Hwy 404 HOV Lane Expansion & Rehab (16th Avenue)	Yes	Yes
11	Hwy 404 HOV Lane Expansion & Rehab (Rouge River)	Yes	Yes
12	South Saugeen River Bridge Replacement, Highway 89	Yes	Yes
13	South Canal Bridges	Yes	Yes
14	Hwy 427 over Rainbow Creek- NBL & SBL	Yes	Yes
15	Langstaff Road Underpass	Yes	Yes
16	Hwy 427 over Rutherford Rd.-NBL & SBL	Yes	Yes
17	Hwy 427 over West Robinson Creek-NBL & SBL	Yes	Yes
18	CPR at McGillivray Rd-NBL & SBL	Yes	Yes
19	Hwy 427 over Major Mackenzie Drive-NBL & SBL	Yes	Yes
20	Major Mackenzie Drive over West Robinson Creek	Yes	Yes
21	Anne Street Underpass	Yes	Yes
22	H401 and Dingham Drive Underpass	Yes	Yes
23	16 Mile Creek Crossing, Milton, Ontario	Yes	Yes
24	Bridgepoint Court Bridge, Aurora, Ontario	Yes	Yes
25	CP Bridge at Major McKenzie Drive, Vaughan, Ontario	Yes	Yes
26	Gordie Howe International Bridge, Windsor, Ontario	Yes	Yes
27	Keith Bridge over E. Holland R. East Abutment, Newmarket, Ontario	Yes	Yes
28	Ott Rd. Bridge Fort Erie, Ontario	Yes	Yes
29	GO Sta. Pedestrian Bridge over Hwy. 401	Yes	Yes
30	Weslie Creek Bridge St. Johns Sideroad, York Region	Yes	Yes
31	H401 Expansion - CP Rail Bridge, WCC20 (24X - 0126 B1,2,3,&4)	Yes	Yes
32	H401 Expansion- CN Rail Overhead Structures	Yes	Yes
33	H401 Expansion - Credit River	Yes	Yes
34	CNR/CPR Structures - Northwest Metro Arterial (1983)	Yes	Yes

Data Collection and Analysis




Data Collection and Analysis

- From all sites, the following information were summarized (Subsurface Condition and Load Transfer Mechanism, Pile information, Driving Event, Hammer System, Hammer Rated Energy, Driving Resistance)



Data Collection and Analysis

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 10% Pile Diameter	2600 2300	Target cumulatie pile displacement reached (30 mm)		
ASTM D1143M Maintained Test	Davisson Offest 10% Pile Diameter	3300 2750	Flanges of test pile yielded at final load increment (200% design load)		
Event		Date	Location		
Pile Installed		Nov. 4, 2019	Design Tip Elev. (m)		
Hiley/PDA EOID		Nov. 4, 2019	ULS Res., FIDR* (kN)		
Hiley/PDA BOR		Nov. 11, 2019	North Abut.		
PLT: Quick Test		Dec. 10, 2019	229		
PLT: Maintained Test		Jan. 13-14, 2019	200		
Pier			229		
			200		
South Abut.			229		
			200		
Pile Type:		End Bearing			
Bearing Stratum:		Cohesionless			
					



Data Collection and Analysis

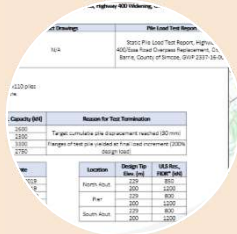
Vert. Vertical Pile
 EOID = End of Initial Drive
 BOR = Beginning of Restrike

BOR = Beginning of Restrike

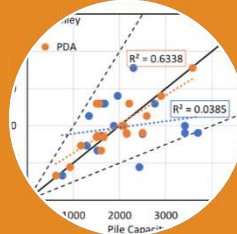
Pile Information										
Pile No.	Pile Location	Pile Specification	Total Pile Length while driving (m)	Final Pile Length After Cutoff (m)	Embedment Length (m)	Total Pile Weight While Driven (kN)	Driving Shoe/Bearing Point	Splice Location/ Depth (m)	Approximate Ground Elevation (m)	Pile Tip Elevation (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 (for PDA test)							Pile Driving Details			
Pile No.	Hammer Specification (For PDA)	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		

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

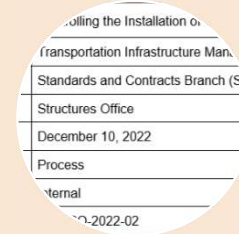
Data Analysis and Results



Data
Collection



Data Analysis
and Results



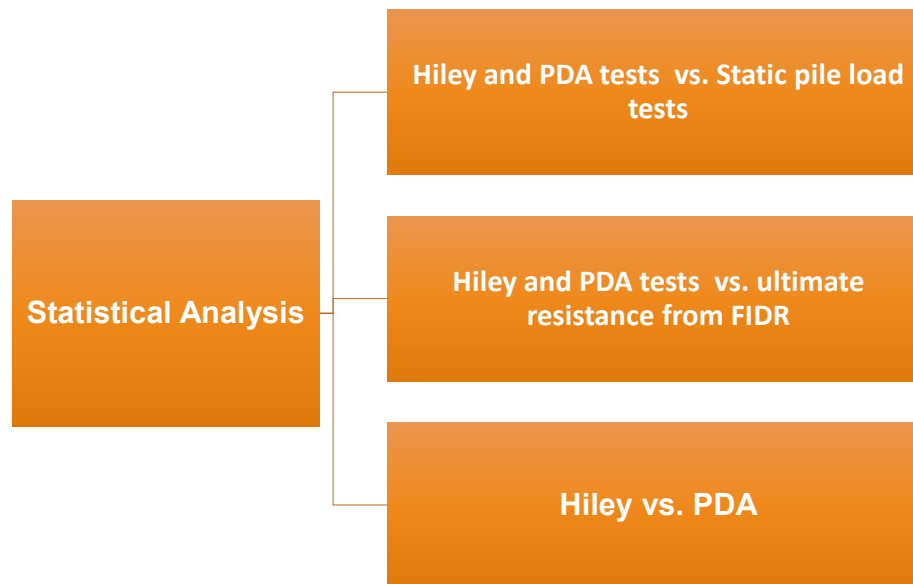
PDA Policy

Data Analysis and Results

Statistical Analysis Procedure

Data Analysis and Results

Statistical Analysis Procedure



Data Analysis and Results

Statistical Analysis Procedure

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 comparison (i.e., one static load corresponds to one PDA test and one Hiley test).
- 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.

Data Analysis and Results

Statistical Analysis Procedure

1) Hiley and PDA vs. Static Pile Load Tests

- Load Ratio

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

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

- Percentage of Error

% of Error – Hiley test

$$= \frac{(\text{Pile capacity, Static} - \text{Pile capacity, Hiley})}{\text{Pile capacity, Static}} \times 100$$

% of Error – PDA test =

$$\frac{(\text{Pile capacity, Static} - \text{Pile capacity, PDA})}{\text{Pile capacity, Static}} \times 100$$

- Linear regression analysis
- Average, Min, Max,
- Standard Deviation, σ
- Coefficient of Variation, COV
- Coefficient of Determination, R^2

Data Analysis and Results

Statistical Analysis Procedure

2) Hiley and PDA vs. Ultimate Resistance from FIDR

- 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 formulas informed by previous experience and related engineering judgement.
- Although static formulas 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.
- In total, 264 sets of tests containing both PDA and Hiley were used in the analysis.

Data Analysis and Results

Statistical Analysis Procedure

2) Hiley and PDA vs. Ultimate Resistance from FIDR

- Load Ratio

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

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

- Percentage of Error

% of Error – Hiley test

$$= \frac{(\text{Pile capacity, FIDR} - \text{Pile capacity, Hiley})}{\text{Pile capacity, FIDR}} \times 100$$

% of Error – PDA test =

$$\frac{(\text{Pile capacity, FIDR} - \text{Pile capacity, PDA})}{\text{Pile capacity, FIDR}} \times 100$$

- Linear regression analysis
- Average, Min, Max,
- Standard Deviation, σ
- Coefficient of Variation, COV

Data Analysis and Results

Statistical Analysis Procedure

3) Hiley vs. PDA

- A total of 284 points were used in the analysis

- Load Ratio

$$\text{Load ratio – Hiley to PDA} = \frac{\text{Pile capacity, Hiley}}{\text{Pile capacity, PDA}}$$

- Percentage of Error

% of Error

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

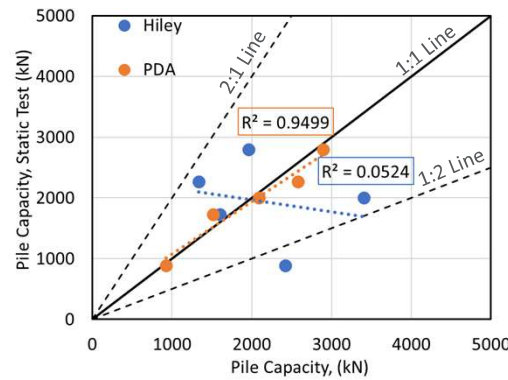
- Linear regression analysis
- Average, Min, Max,
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Data Analysis and Results

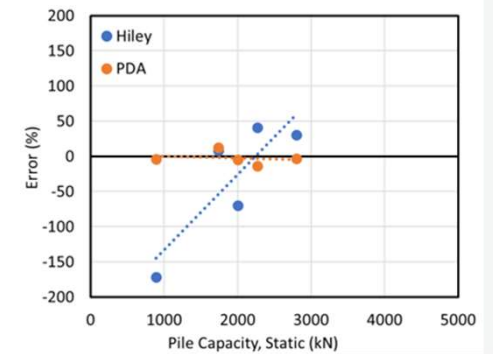
Statistical Analysis Procedure

The results are presented in forms of:

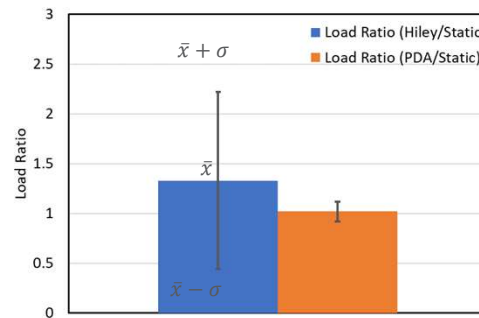
- Scatter Chart:
- Column Chart:
- Tables



Sample of pile load capacity, Hiley or PDA vs. Pile capacity, Static



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

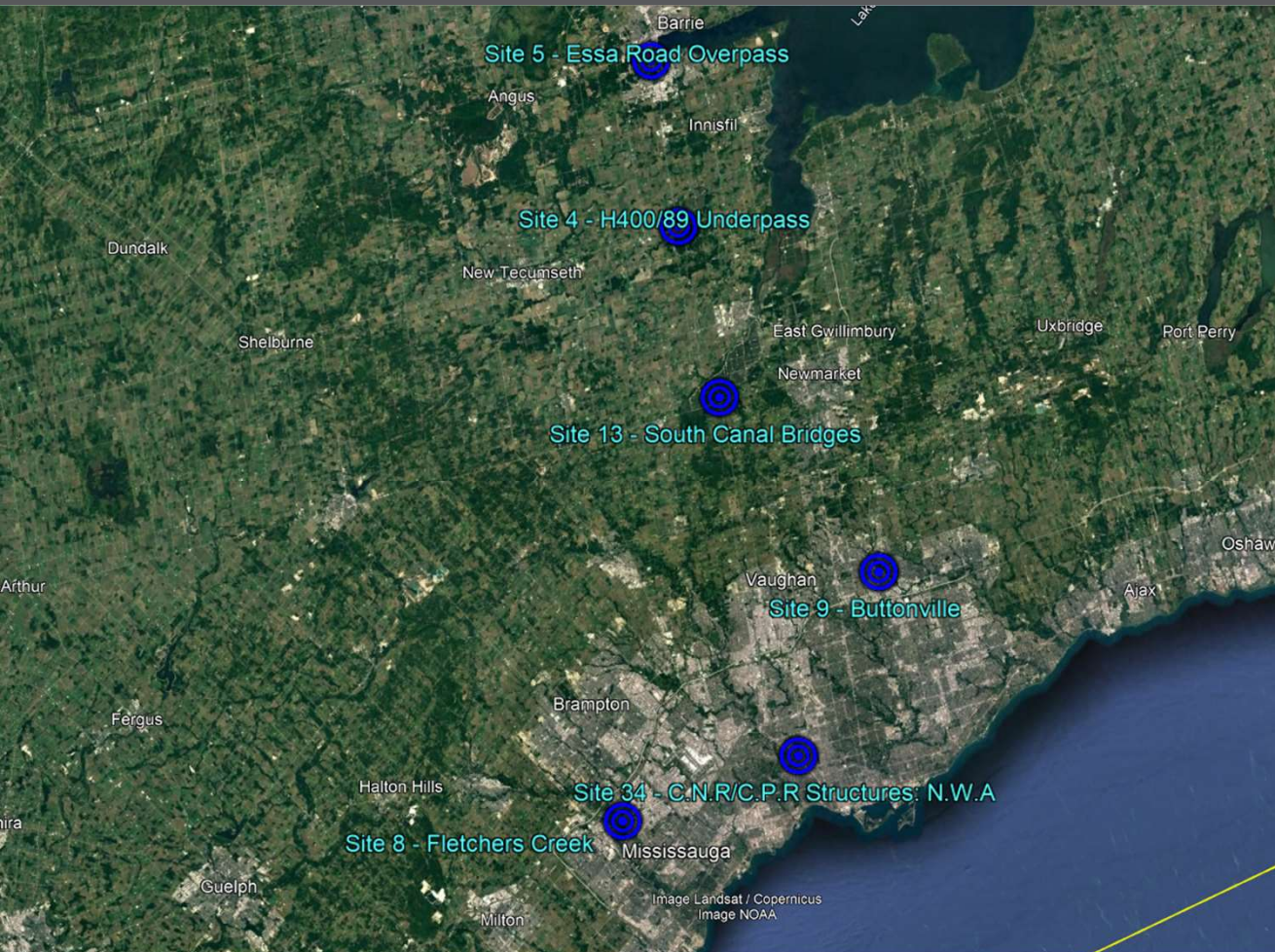


Sample of load ratio results

Data Analysis and Results

Selected Results Hiley and PDA vs. Static Pile Load Tests

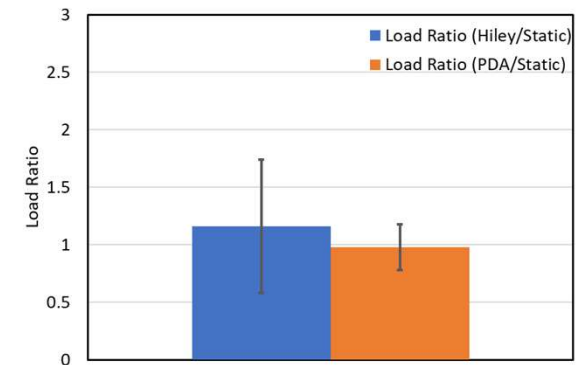
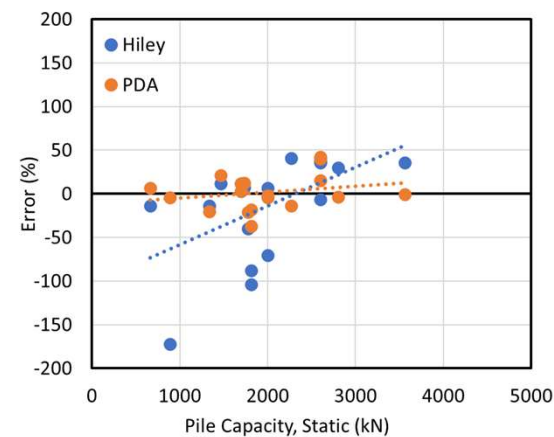
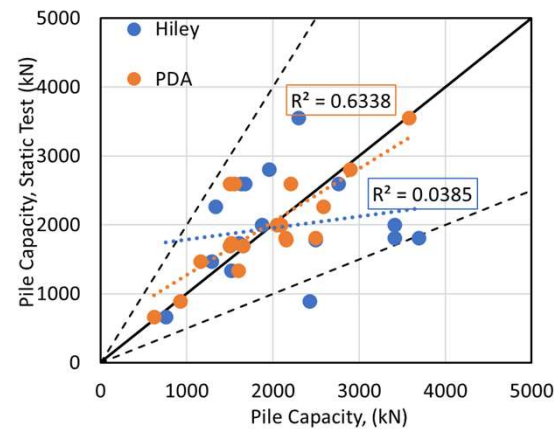
Data Analysis and Results



- The data from these sites (site 4, 5, 8, 9, 13 and 34) were used as benchmarks for statistical analysis in this presentation.
- These sites contains PDA, Hiley and Pile Load Tests data.

Data Analysis and Results

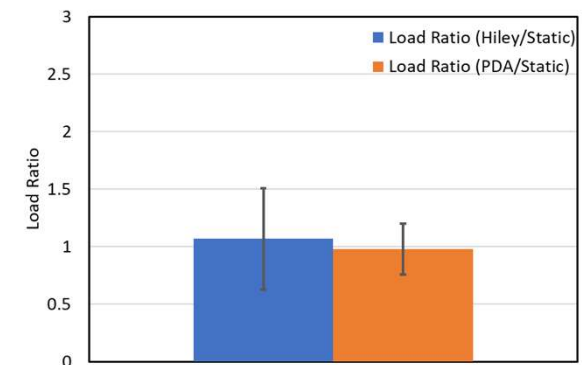
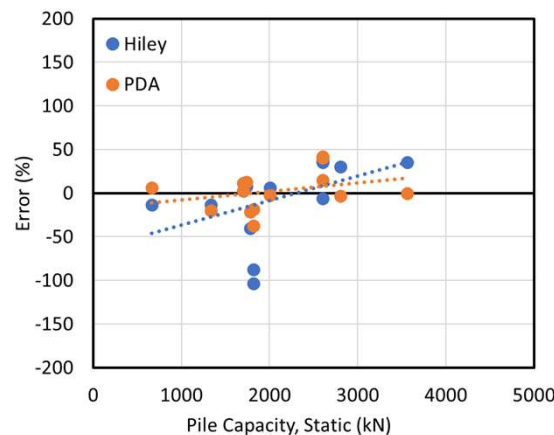
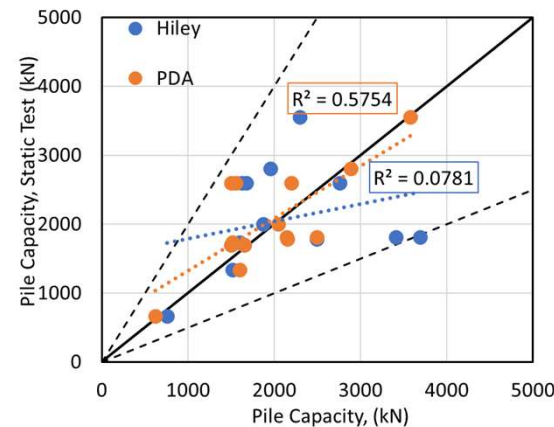
- The results of PDA tests were aligned with the 1:1 Line with a R^2 value of 0.63, while the results obtained from Hiley tests showed poor agreement with respect to the pile capacity results obtained from static load tests with a very low R^2 value (0.04).
- The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near both the 1:2 and 2:1 line.
- 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%.
- PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test.



All Data

Data Analysis and Results

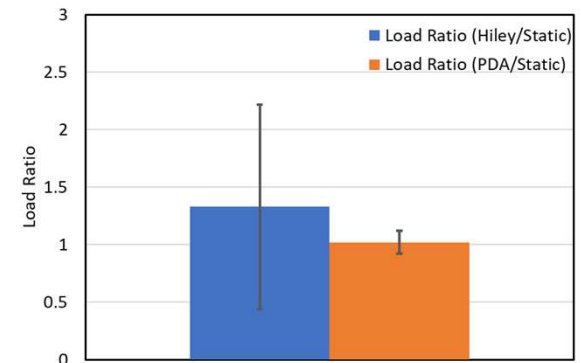
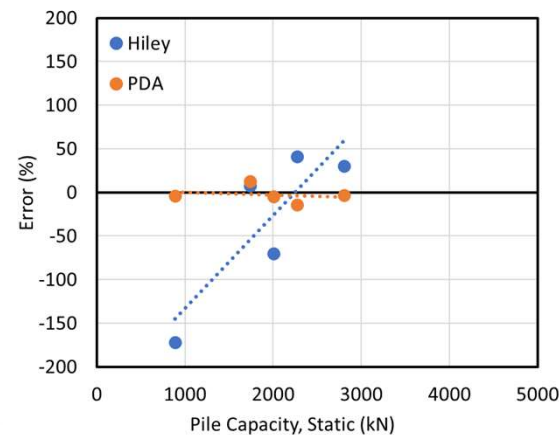
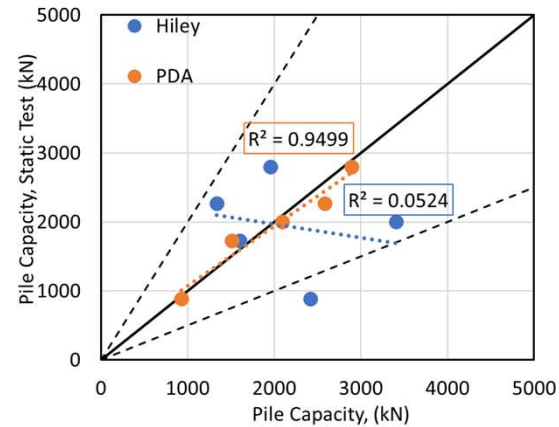
- PDA tests were aligned with the 1:1 Line with R^2 of 0.58, while the results obtained from Hiley tests showed poor agreement with respect to the pile capacity results obtained from the static load test with a very low R^2 value (0.08).
- The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near both the 1:2 and 2:1 line.
- 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%.
- 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 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.



**End Bearing Piles –
Cohesionless Soil**

Data Analysis and Results

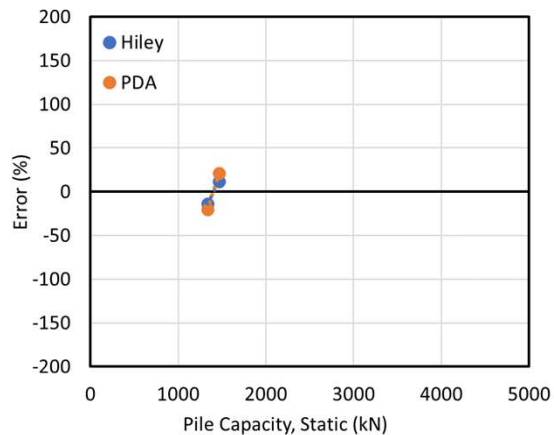
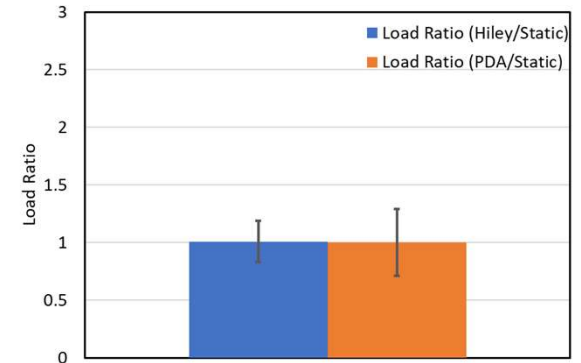
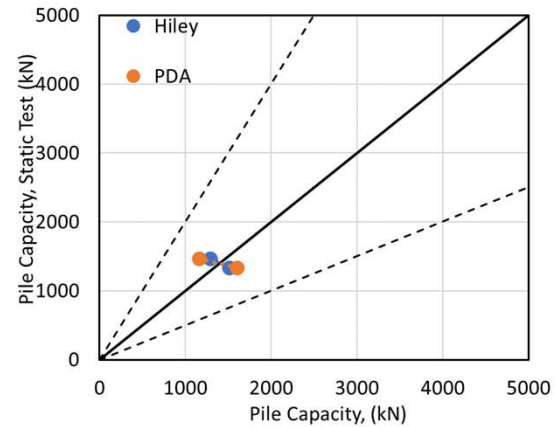
- PDA tests were aligned well with the 1:1 Line with a R^2 of 0.95, while the results obtained from Hiley tests showed poor agreement with respect to the pile capacity results obtained from the static load test with a very low R^2 value (0.05).
- The results obtained from Hiley tests showed a higher level of scatter with considerably more data points landing near both the 1:2 and 2:1 line.
- 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%.
- PDA results showed a lower range of error compared to Hiley results with respect to the pile capacity obtained from the pile load test.



**Friction Piles – Layered
Soil Strata**

Data Analysis and Results

- 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. However, no conclusive discussion can be made based on two points. More data is required to have a clear conclusion.



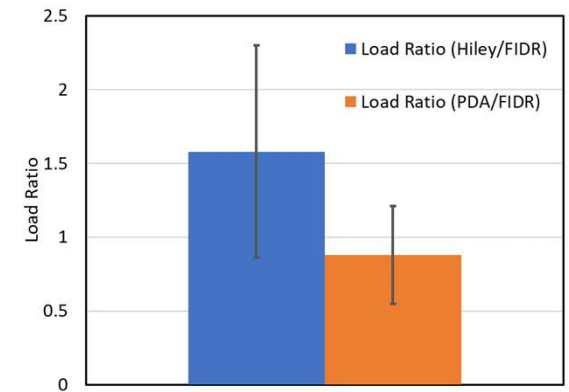
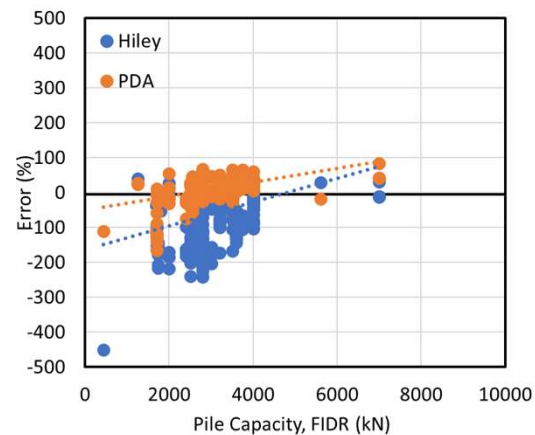
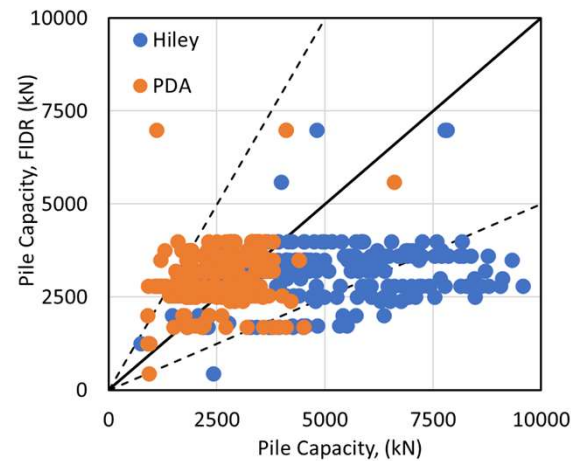
**Friction Piles –
Cohesionless Soil**

Data Analysis and Results

Selected Results **Hiley and PDA Tests vs. FIDR ULS Resistance of Piles**

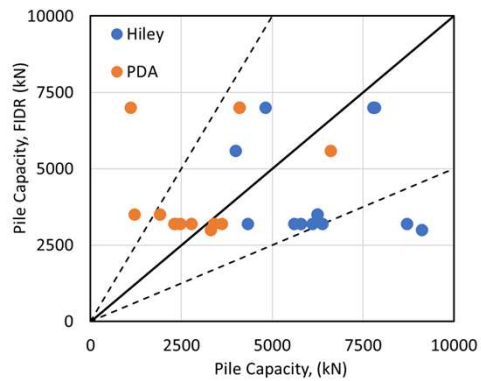
Data Analysis and Results

- 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.
- 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%.
- PDA test results showed a lower range of error compared to Hiley results on average.

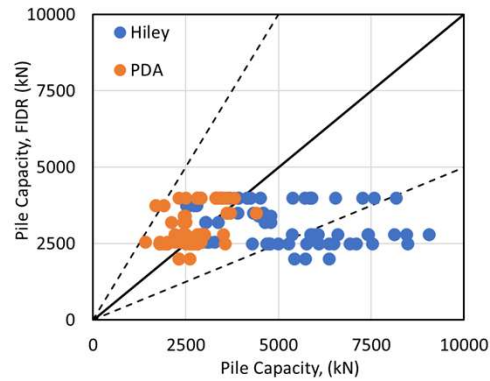


All Data

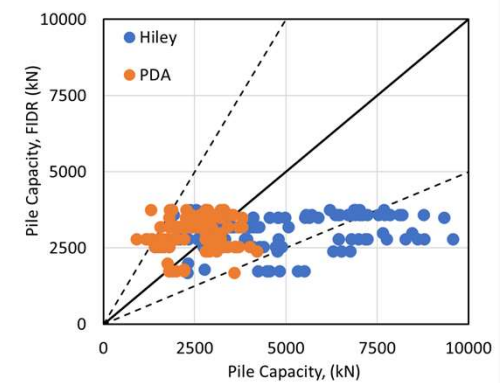
Data Analysis and Results



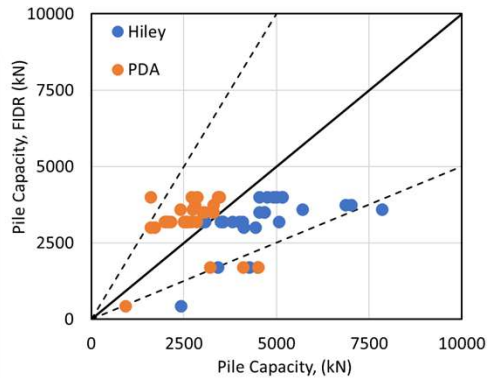
End Bearing - Bedrock



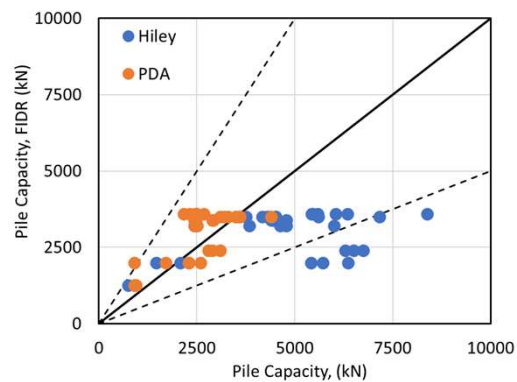
End Bearing - Cohesive Soil



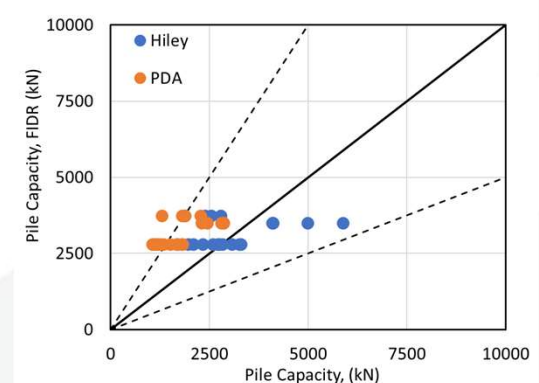
End Bearing - Cohesionless Soil



Friction Piles - Layered Soil

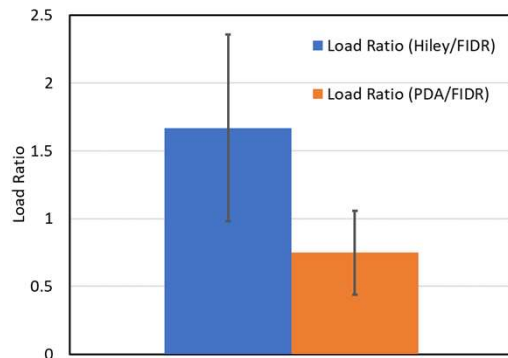


Friction Piles - Cohesive Soil

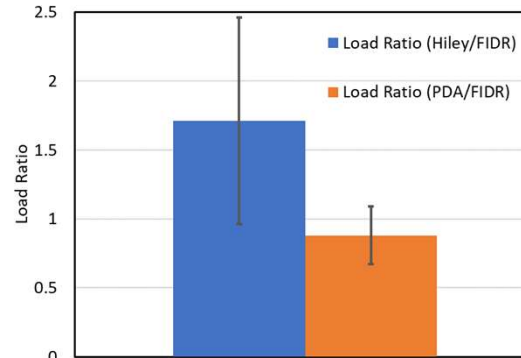


Friction Piles - Cohesionless Soil

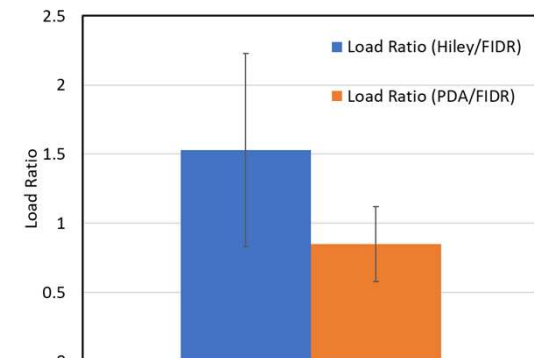
Data Analysis and Results



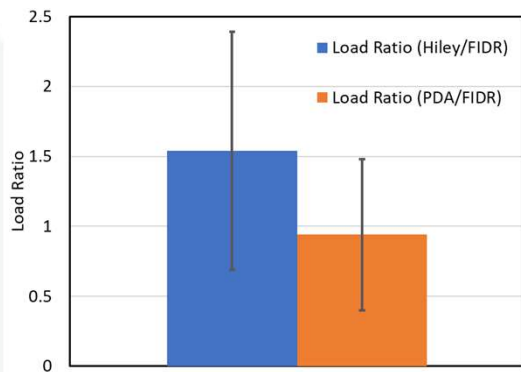
End Bearing - Bedrock



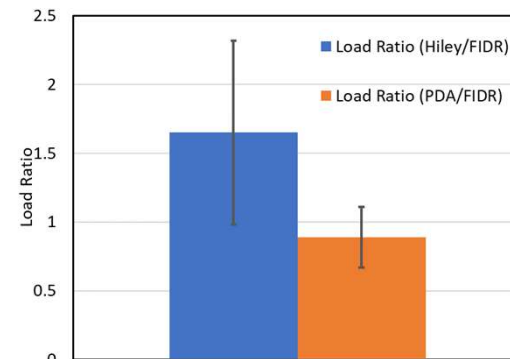
End Bearing - Cohesive Soil



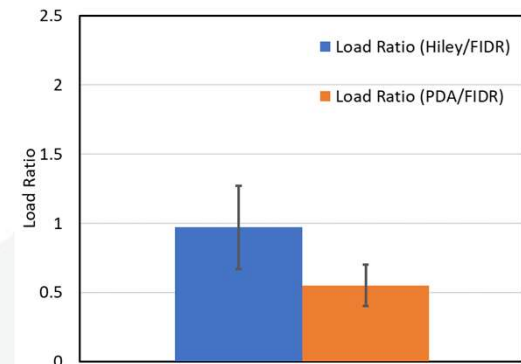
End Bearing - Cohesionless Soil



Friction Piles - Layered Soil



Friction Piles - Cohesive Soil



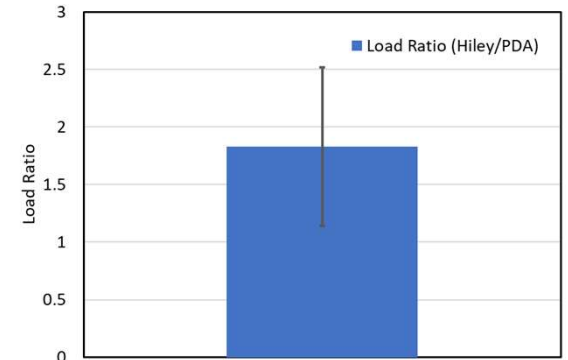
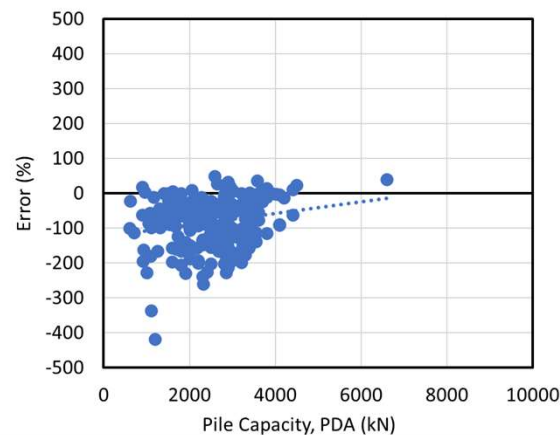
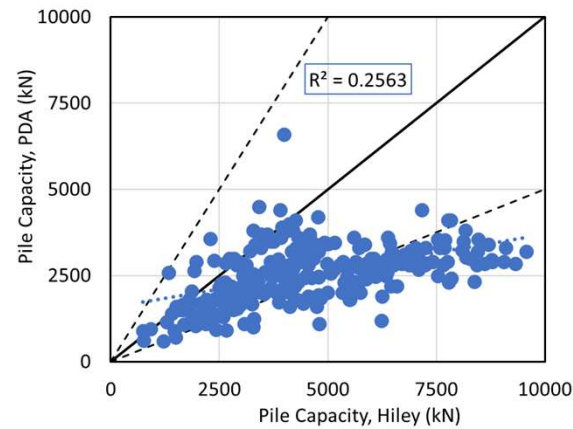
Friction Piles - Cohesionless Soil

Data Analysis and Results

Selected Results Hiley vs PDA

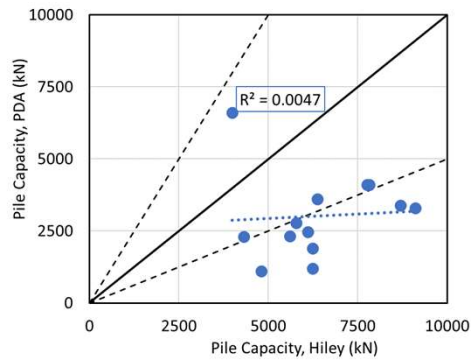
Data Analysis and Results

- 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 PDA tests.
- 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.
- Wide range of the percentage of error of Hiley geotechnical capacity with respect to the PDA geotechnical capacity based on all data.

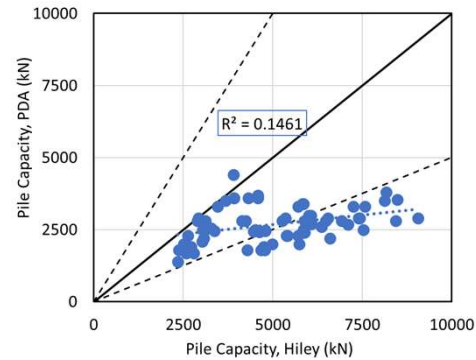


All Data

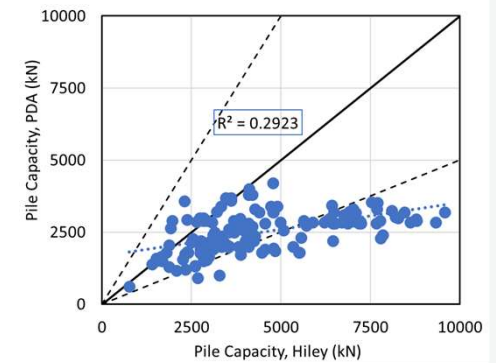
Data Analysis and Results



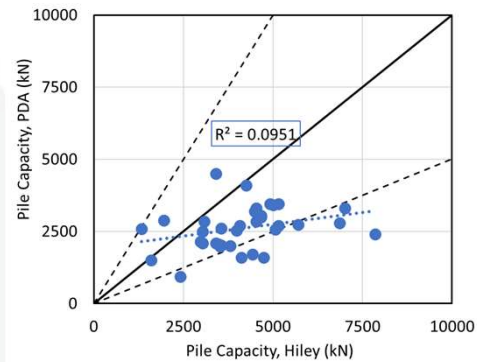
End Bearing - Bedrock



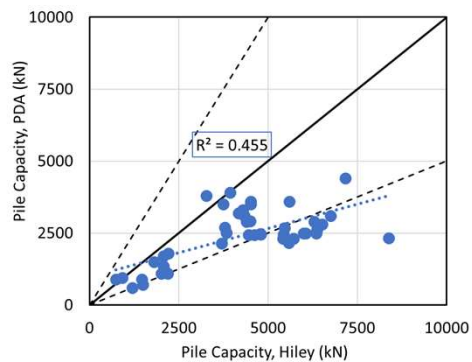
End Bearing - Cohesive Soil



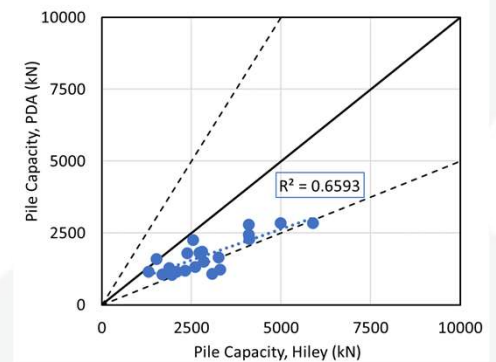
End Bearing - Cohesionless Soil



Friction Piles – Layered Soil

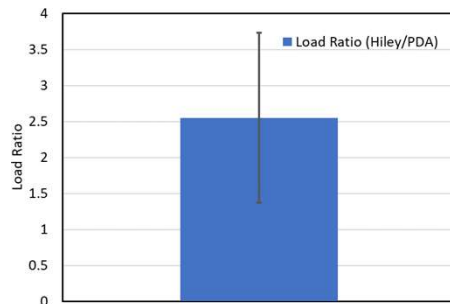


Friction Piles - Cohesive Soil

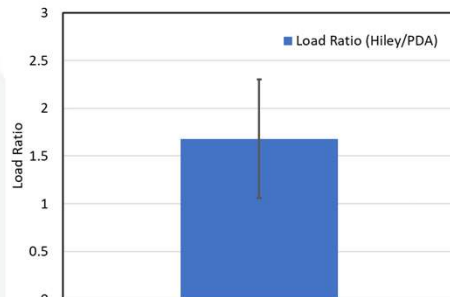


Friction Piles - Cohesionless Soil

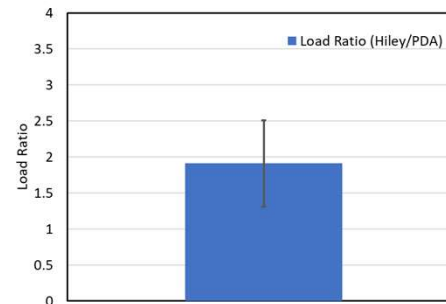
Data Analysis and Results



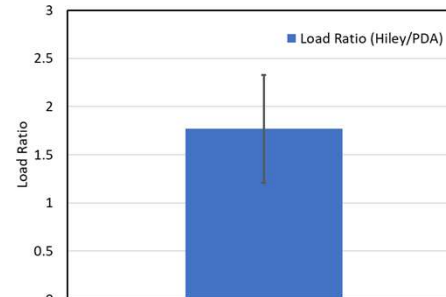
End Bearing - Bedrock



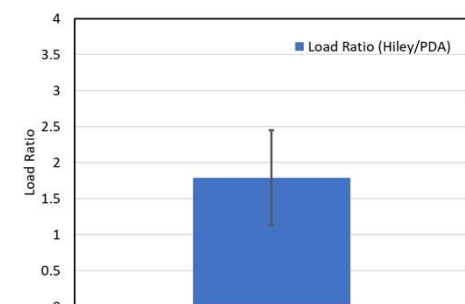
Friction Piles – Layered Soil



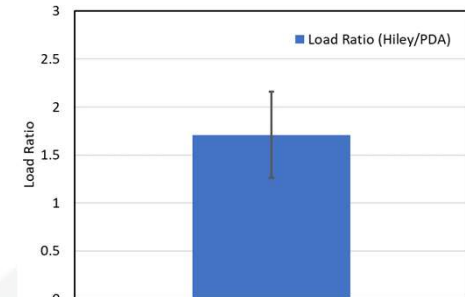
End Bearing - Cohesive Soil



Friction Piles - Cohesive Soil



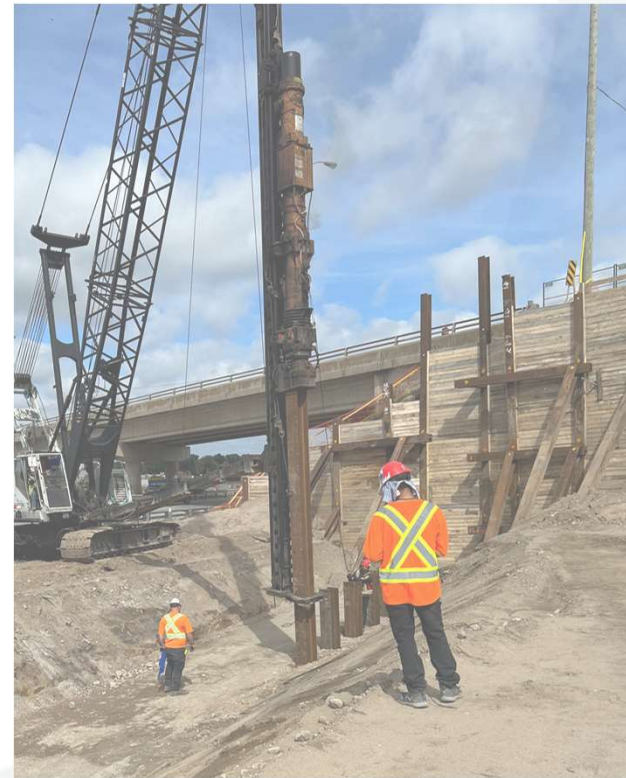
End Bearing - Cohesionless Soil



Friction Piles - Cohesionless Soil

Agenda

- 01 Introduction
- 02 Motivation and Objectives
- 03 Methodology
- 04 Data Collection and Analysis
- 05 **Summary of the Results**
- 06 Conclusions and Recommendations



Summary of Results

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.
		Vertical Piles	NA	PDA	Not Matching (overestimate)	

Summary of Results

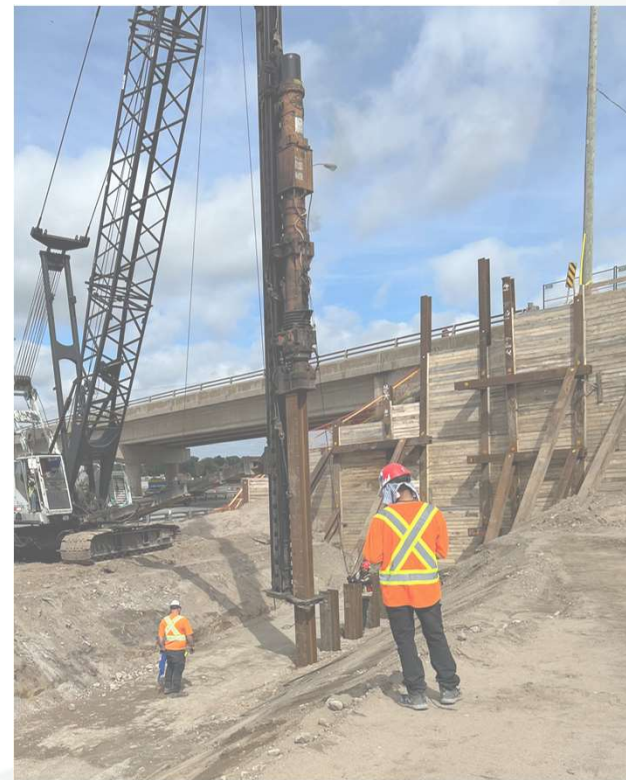
No	Parameter	Sub - Parameter	Best Match Method According to:		Hiley to PDA	Comments
			Static	FIDR		
4	Pile Type	H-Piles	PDA	PDA	Not Matching (overestimate)	
		Pipe Piles	PDA	PDA	Not Matching (underestimate)	1. Sample size based on limited data (3-points) for static tests.
		Precast Concrete Piles	PDA	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	$L \leq 12$ 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.
		$12 \text{ m} < L \leq 24$ m	PDA	PDA	Not Matching (overestimate)	
		$24 \text{ m} < L \leq 36$ m	PDA	PDA	Not Matching (overestimate)	
		$36 \text{ m} < L \leq 60$ 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 and 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.

Summary of Results

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	

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Conclusions and Recommendations

1. Overall, the study concluded that the PDA is a more reliable and dependable method of controlling pile installation.
2. PDA shall be the preferred approach of controlling the installation of piles on MTO projects with exceptions as described below
 - a) When it is well supported by empirical correlations under a giving set of physical and geological conditions.
 - b) Where a site-specific correlation has been obtained for hammer, soil, pile system with static load test.
 - c) Friction piles in cohesionless soils.
 - d) Low complexity projects at remote locations.
 - e) Piles driven to hard bedrock.
 - f) End bearing H-piles driven by drop hammer in relatively low complexity projects.

For above applications, modified Hiley may continue to be used.

3. A draft policy has been developed under direction and in cooperation with MTO foundations.

Suggesting Replacement:

Title:	Controlling the Installation of Driven Piles.
Division:	Transportation Infrastructure Management Division (TIM)
Branch:	Standards and Contracts Branch (SCB)
Office:	Structures Office
Date:	December 10, 2022
Theme(s):	Process
Distribution:	Internal
Memo #:	SCB-SO-2022-02

5. PDA Test Procedure, Qualifications and Reporting

a) Procedure

PDA testing shall be completed in accordance with ASTM D4945 or as specified.

The impact device used for PDA testing shall be acceptable to the Contract Administrator and capable of mobilizing the ultimate pile capacity in a single blow without additional data interpretation.

The number of PDA tests to be completed shall be specified.

PDA testing shall be completed at the end of initial driving and upon re-strike when re-striking is specified in the Special Provisions of the Contract.

PDA testing shall be carried out to verify axial capacity, energy transferred to pile and/or pile integrity as specified.

b) Qualifications

The execution of the PDA requires experience and qualifications.

The high strain dynamic 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).

High-strain dynamic 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.

Suggesting Replacement:

High-strain dynamic tests shall be performed under the direction of an Engineer with at least 5 years of experience in high-strain dynamic testing and holding a proficiency rating at the intermediate level and/or better for dynamic measurement analysis proficiency test as administered by the Pile Driving Contractors Association (PDCA). After December 31, 2023, the Engineer shall be required to hold a proficiency rating level of Advanced or better.

Questions

