Long-term Lateral Resistance of Helical Piles in Cohesive Soils

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ABSTRACT
The results of ten lateral pile load tests for both helical piles and driven piles with the same shaft diameter and wall thickness are presented in this paper. The long term lateral load tests were conducted four years after the piles were installed. The test program was consisted of 6 long-term and 2 short-term helical pile loads tests and 2 long-term driven pile load tests. The test results show that both helical and driven piles have similar long-term lateral behavior. This study confirmed the previous research findings that shaft diameter and embedment depth primarily control the lateral resistance of both helical piles and driven piles. The long-term lateral resistance of the helical piles was equal to or exceeded that of the driven piles. In comparing the short-term and long-term lateral resistance of the helical piles, the long-term test results showed an average of 10% to 20% increase in lateral resistance, four years after installation.

RÉSUMÉ
Les résultats de dix tests de résistance latérale pour pieux vissés et battus, utilisant le même diamètre de tuyau et la même épaisseur de mur sont présentés dans ce document. Ces tests de résistance latérale ont été complétés quatre ans après l'installation des pieux. Ces résultats démontrent que les pieux vissés ont le même comportement à long-terme que les pieux battus. L'étude a reconfirmé les résultats des recherches précédentes qui démontrent que le diamètre du pieu est le principal point de résistance du contrôle latérale des pieux vissés et battus. Par ailleurs, les résultats des tests ont aussi démontrés que la résistance latérale à longue durée des pieux vissés est égale, ou même plus élevée que celle des pieux battus. En comparant la résistance à courte et à longue durées des pieux vissés, les résultats indiquent une augmentation moyenne de 10 à 20% de la résistance latérale, quatre ans à la suite de l'installation.

1 INTRODUCTION

Recent development of hydraulic torque motors, coupled with advances in manufacturing techniques, now allows for the use of large diameter helical piles (up to 42" shaft diameter). Large diameter helical piles can be used in a wide variety of applications that require combined high compressive and tensile loading, as well as large lateral loading. Deep foundation application examples include wind turbines, power transmission towers, pipeline anchor blocks, and many others.

Many publications have focused on the compression and uplift capacity of helical piles, while few studies have examined short-term lateral resistance, and none have examined long-term lateral resistance. Investigation of the long term lateral performance of helical piles is necessary in order to evaluate any improvement in lateral resistance over time.

G. Padros et al. (2012) evaluated the lateral load performance of screw piles in cohesive soils by considering the soil disturbance from pile installation in terms of soil sensitivity. Continuing from that research, the results of a series of helical pile lateral load test programs, for both long-term and short-term durations after pile installation, are presented. The results for helical piles were also analyzed and compared to results for the long term lateral capacities of driven piles with the same shaft diameter.

In November 2008, 6 helical piles and 2 driven piles were installed, to be used as long-term test piles (-LT). In July 2012, 2 helical piles were installed, to be used as short-term test piles (-ST). The lateral load tests were conducted in July 2012, only a few days after the two short-term screw piles were installed, and almost 4 years after the long-term piles were installed.

2 TEST SITE AND GEOTECHNICAL CONDITIONS

The test site is located about 11.0 km (7 miles) to the north of Ponoka, Alberta (Figure 1). The subsurface investigation was conducted using cone penetration testing (CPT) and a mechanically augured test hole to a depth of 15.0m.

The soil stratigraphy consists of an upper 1.0m thick layer of organic silt, underlain by 2.0m of stiff clay, followed by a 1.5m layer of very stiff silty clay, and followed by a 7.5m thick layer of hard clay till. The ground water level was measured at 1.2m below the existing ground surface. The soil properties are summarized in Table 1:

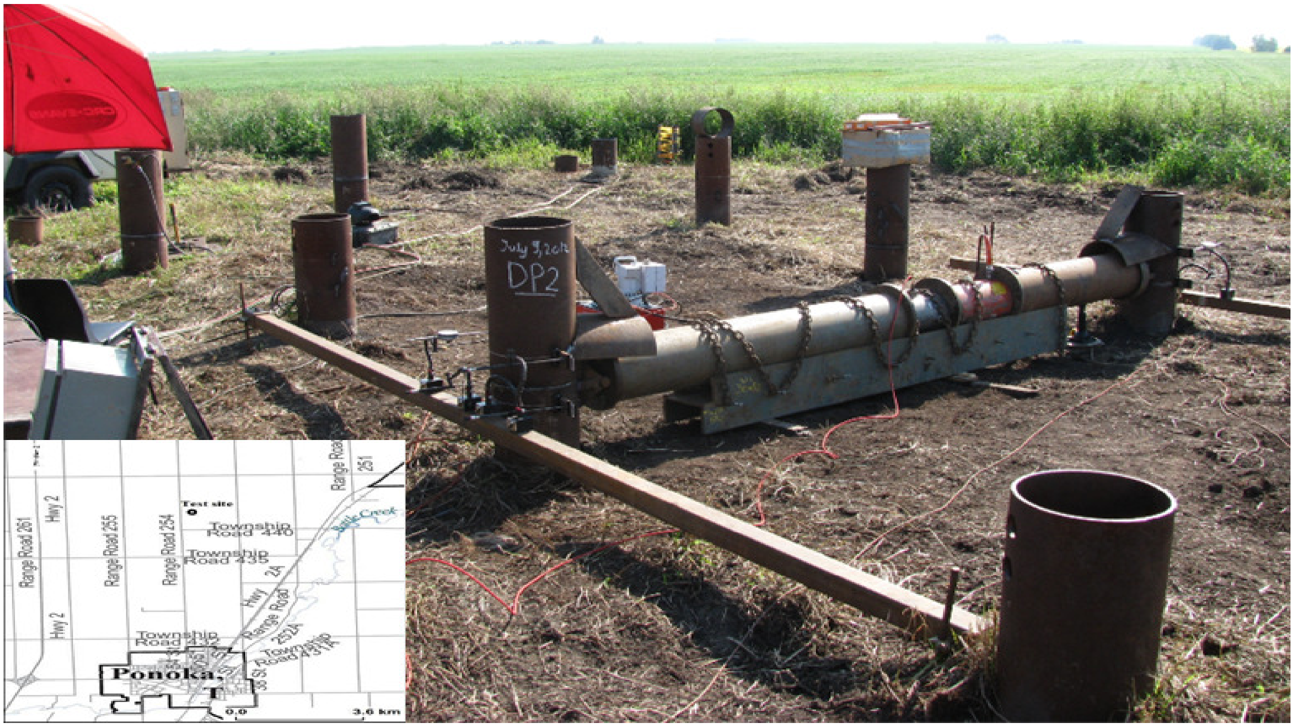

Figure 1: Test site location

Soil Type	Depth	Total Unit Weight	Undrained Shear Strength	Frictional Angle
	m	kN/m^3	kPa	(degree)
Organic silt, soft	0.0-1.0	17.5	-	28
Clay, stiff	1.0-3.0	17.8	85	-
Silty clay, very stiff	3.0-4.5	17.8	137	-
Clay till, stiff to hard	4.5-12	18.2	-	42

Table 1: Summary of soil properties

3 TEST SETUP

The lateral pile load tests were conducted in general accordance with ASTM D3966-07, Standard Method of Testing Deep Foundations under Lateral Loads, Procedure A. A typical lateral load test setup is shown in Figure 2. The test was setup in order to test two piles simultaneously. The piles were installed about 3.0m away from each other. The reaction piles were placed strategically to allow them to be utilized for a number of different test piles. This arrangement reduced the amount of time required to carry out the testing program. The horizontal load was applied using a 200 ton hydraulic jack located approximately 0.3m above the ground surface.

Lateral deflection was monitored at three points along the pile stick-up length: at grade level 300mm, and 500mm above the ground surface. The lateral movements were measured by three linear displacement transducers (LDTs) with 0.01mm accuracy, and a dial gauge with 0.025mm subdivisions.

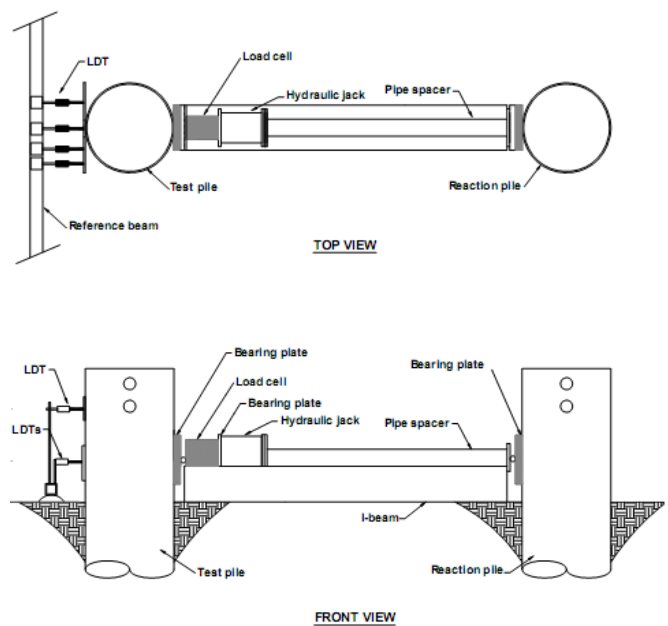

Figure 2: Typical lateral test setup

Pile Type	Length (m)	Shaft Dia. (mm)	Wall thick. (mm)	Helix Dia. (mm)	No. of Helices	Spacing Ratio (S/D)	Stick Out (m)	Embed. Dep. (m)	Soil Plugged (m)
HP1-LT	7.1	324	9.5	914	2	3	0.74	6.36	4.3
HP2-LT	7.4	324	9.5	914	2	3	1	6.40	3.8
HP3-LT	9.5	324	9.5	610	2	3	0.58	8.92	2.3
HP4-LT	9.1	324	9.5	914	2	3	1.1	8.00	5.8
HP5-LT	7.5	324	9.5	762	2	3	0.5	7.00	-
HP6-LT	9	324	9.5	610	1	-	0.3	8.70	0.3
DP1-LT	9	324	9.5	-	-	-	0.3	8.70	-
DP2-LT	6	324	9.5	-	-	-	0.3	5.70	2.4
HP7-ST	7.1	324	9.5	914	2	3	0.6	6.50	4.3
HP8-ST	7.1	324	9.5	914	2	3	0.6	6.50	4.3

Table 2: Summary of tested helical pile configuration and installation

4 HELICAL PILE CONFIGURATION AND INSTALLATION

The test helical piles were fabricated and installed by ALMITA Piling Inc., Ponoka, Alberta. Helical piles are installed by applying a turning moment (torque) to the central shaft, whereby the helical plate(s) self- advance in a “screwing” motion. A downward force may also be applied to the screw pile during installation to facilitate the “biting” of the helices into the soil and aiding the downward movement of the pile. The pile installation equipment consisted of a hydraulic drive head mounted on a tracked excavator. In this testing program, the maximum torque of the hydraulic drive head was 156 ft.Kips. A summary of tested helical pile configurations are presented in Table 2. Figure 3 illustrates a typical helical pile configuration.

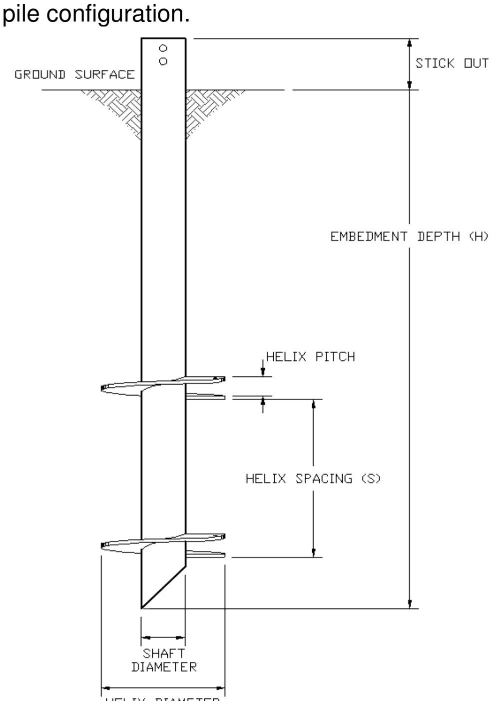

Figure 3: Helical pile configuration

5 TEST RESULTS

The load test results were interpreted and analyzed to understand the long-term behaviour of helical piles under lateral loading. Concurrently, the long-term lateral performance of driven piles was investigated. For comparison purposes, the long-term (typically 4 years after installation) and short-term load-lateral deflection curves were plotted together to showcase the lateral resistance improvement of the tested helical piles over time.

5.1 Lateral Load –Deflection Curves

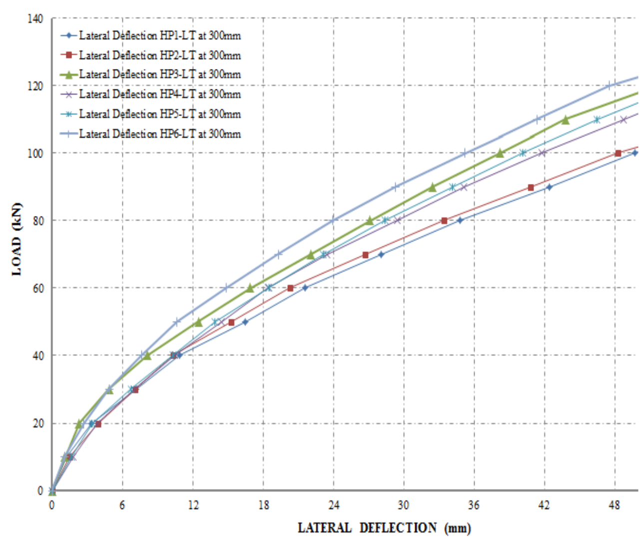

Figure 4: Lateral load-deflection curves for helical piles HP1-LT, HP2-LT, HP3-LT, HP4-LT, HP5-LT and HP6-LT

As can be seen from Figure 4, the lateral resistance of helical piles HP1-LT and HP2-LT were approximately equal to each other, and likewise for piles HP4-LT and HP5-LT. It can be observed that the lateral behavior of the shorter helical piles (HP1-LT, HP2-LT, HP4-LT and HP5-LT) were very similar up to 12mm lateral deflection.

It should be noted that piles HP1-LT, HP2-LT, HP4-LT and HP5-LT all have the same shaft diameter, same number of helices, and were installed to nearly the same final embedment depths. The lateral resistance of helical piles HP3-LT and HP6-LT was about 12% to 30% higher than that of the other 4 helical piles. The increase in lateral resistance of HP3-LT and HP6-LT is likely due to the deeper embedment depths.

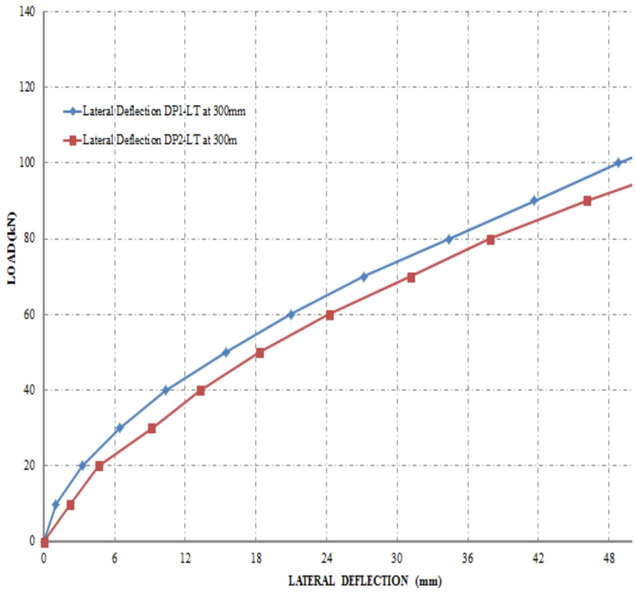

Figure 5: Lateral load-deflection curves for driven piles DP1-LT and DP2-LT

The load test results for the two driven piles were interpreted, and are presented in the Figure 5. It should be noted that piles DP1 and DP2 had the same pipe diameters, but had different final embedment depths. Pile DP1-LT was installed 3m deeper than DP2-LT. Similar to the results for the helical piles HP3-LT and HP6-LT, the lateral resistance of the longer driven pile DP1-LT was about 15% higher than that of DP2-LT. This observation reconfirmed that the lateral behavior of helical piles and driven piles are the same, and that lateral resistance is governed primarily by shaft diameter and final embedment depth.

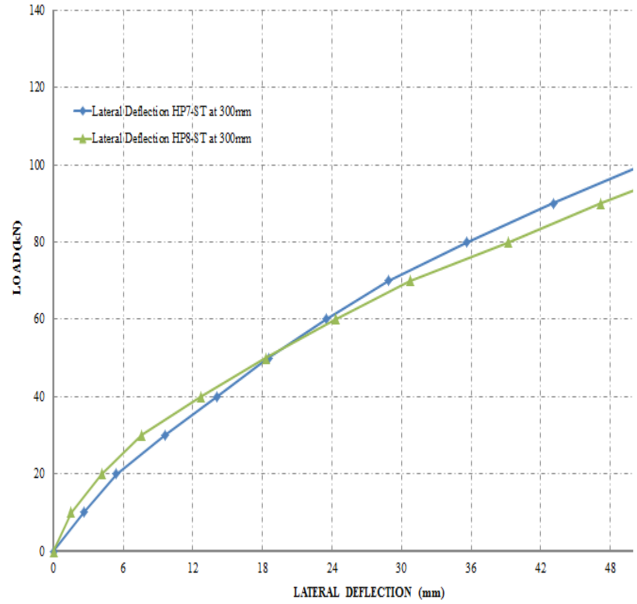

Figure 6: Lateral load-deflection curves for helical piles HP7-ST and HP8-ST

In July 2012, helical piles HP7-ST and HP8-ST were installed shortly before conducting the lateral load tests. The test results for these two piles are shown in Figure 6. With both piles having the same configuration and embedment depth, the resulting lateral load-deflection curves are nearly identical. The two curves cross each other at a lateral deflection of 20mm. The results for HP7-ST and HP8-ST are representative for short-term lateral resistance. Short-term and long term lateral load test results will be compared to investigate the long-term lateral capacity improvement of helical piles in section 6.

5.2 Lateral Resistance of Tested Piles

According to the Canadian Foundation Engineering Manual (2006), the lateral capacities of piles may be limited by the following factors: the lateral capacity of soils, the maximum bending moment that exceeds the structural capacity of the pile, or the maximum allowable deflection at the pile heads. Typically for helical piles, the lateral deflection criterion depends on the type of application. For oil and gas projects, usually the allowable

Pile ID	Lateral loads (kN) at different deflection levels (measured at 300mm above grade)			
	6 mm	12 mm	25 mm	50 mm
HP1-LT	27.0	42.0	65.3	100.3
HP2-LT	26.6	43.5	67.4	101.8
HP3-LT	33.6	48.9	75.8	117.9
HP4-LT	26.9	43.9	72.6	111.8
HP5-LT	27.9	44.7	73.6	115.0
HP6-LT	34.1	53.3	82.0	122.6
DP1-LT	28.7	43.2	66.5	101.5
DP2-LT	23.0	37.0	61.1	94.3
HP7-ST	21.4	35.3	62.8	98.9
HP8-ST	25.4	38.6	61.1	93.3

Table 3: Summary of lateral load test results

lateral deflection is 6mm. For power transmission lines, the lateral deflection criterion could be 12mm or 25mm. Hence, it is of interest to report the lateral loads at deflections of 6mm, 12mm, 25mm and 50mm. The lateral loads at different levels are summarized in Table 3.

6 COMPARISON BETWEEN MEASURED AND ESTIMATED LATERAL RESISTANCES FOR HELICL PILES

The computer program LPILE Plus 6 (2012) was used to predict the lateral behavior of the tested helical piles. The soil parameters used in the analysis are provided in Table 1. The loads were applied at 0.3m above ground surface to simulate the point of lateral load application for a free-head condition. The P-Y multiplier method of LPILE was employed to model and analyse the short-term and long-term lateral behavior of the test piles.

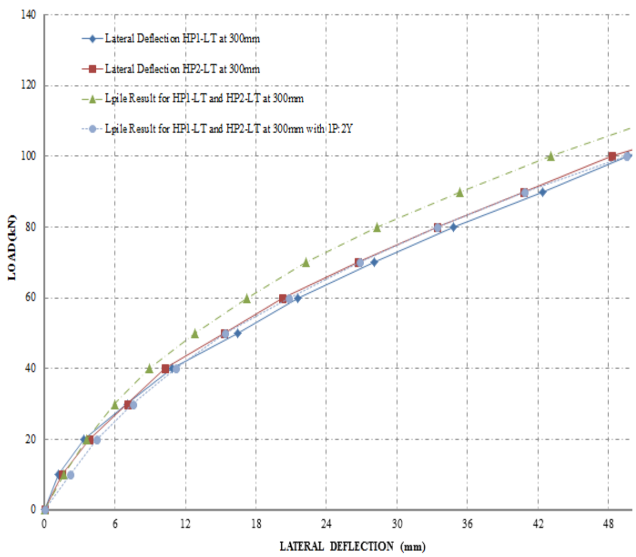

Figure 7: LPILE analysis for HP1-LT and HP2-LT

The LPILE analysis results for pile HP1-LT and HP2-LT are presented in Figure 7. It can be observed that the lateral resistance estimated with an assumption of no soil disturbance (1P-1Y) was about 10% to 15% higher than the measured lateral resistance of the helical piles HP1-LT and HP2-LT, 4 years after their installation. So, it is recommended to take into account soil disturbance when it comes to analyzing lateral resistance of helical piles in practical design. The detailed procedures of how to assess the potential reduction factors was investigated by G. Padros et al. (2012). It can also be seen from Figure 7 that back-analysis LPILE results were in reasonable agreement with the test results by using a Y multiplier of 2.0.

The same approach was applied for the short-term analysis of helical piles HP7-ST and HP8-ST. The LPILE analysis results for HP7-ST and HP8-ST are presented in Figure 8. The estimated LPILE lateral resistance for HP7-ST and HP8-ST compared reasonably well with the values measured from the load tests. A ratio of 1P-3Y multiplier was used for this short-term LPILE lateral analysis.

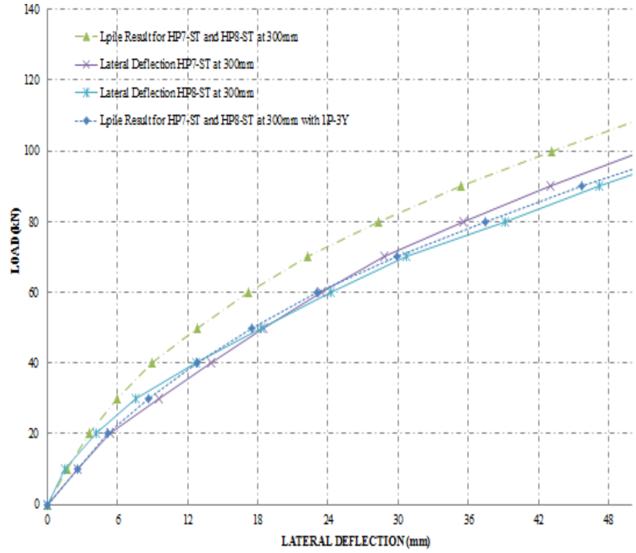

Figure 8: LPILE analysis for HP7-ST and HP8-ST

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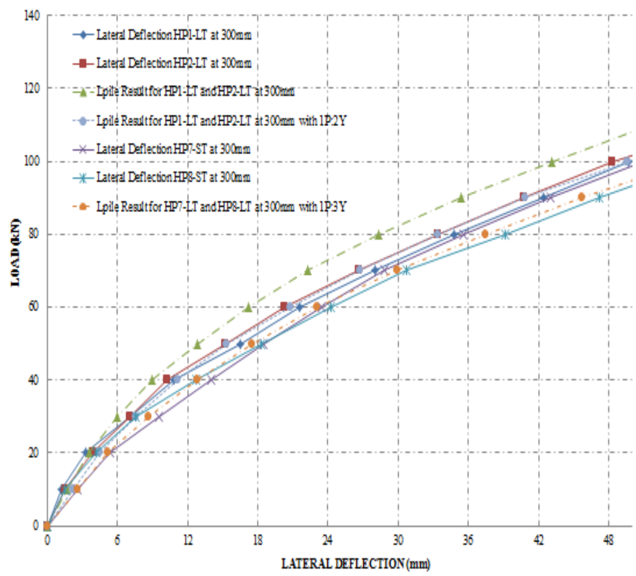

Figure 9: LPILE analysis for HP1-LT, HP2-LT, HP7-ST and HP8-ST

The load test and LPILE results for HP1-LT, HP2-LT, HP7-ST, and HP8-ST were combined together and are shown in Figure 9. These 4 piles have the same pile configuration, and were installed to approximately equal final embedment depths. The experimental data clearly reveals that the long-term (4 years after installation) lateral resistance of piles HP1-LT and HP2-LT increased by approximately 10% to 20%, as compared to the short-term lateral resistance of HP7-ST and HP8-ST. This study is among the first to consider the long-term lateral resistance of helical piles. The results help to understand and quantify the long-term improvement in lateral capacity of the tested helical piles. The results also confirmed findings from previous studies by Sakr (2009) and Sakr (2010) that the P-Y multiplier method of LPILE is able to accurately model the soil disturbance that occurs during pile installation, and is a rational method for quantifying long-term soil recovery.

7 COMPARISON BETWEEN LONG-TERM LATERAL RESISTANCE OF HELICAL PILES AND DRIVEN PILES

As can be seen from Table 2, the pile shaft diameters in this testing program were equal, and the lateral resistance therefore depends primarily on the final embedment depths. For comparison purposes, the results were classified in two groups determined by final embedment depth. The first group included test piles HP1-LT, HP2-LT and DP2-LT which have embedment depths of approximately 6m. The second group included test piles HP3-LT, HP4-LT, HP6-LT, and DP1-LT which have embedment depths ranging from 8.0m to 8.9m.

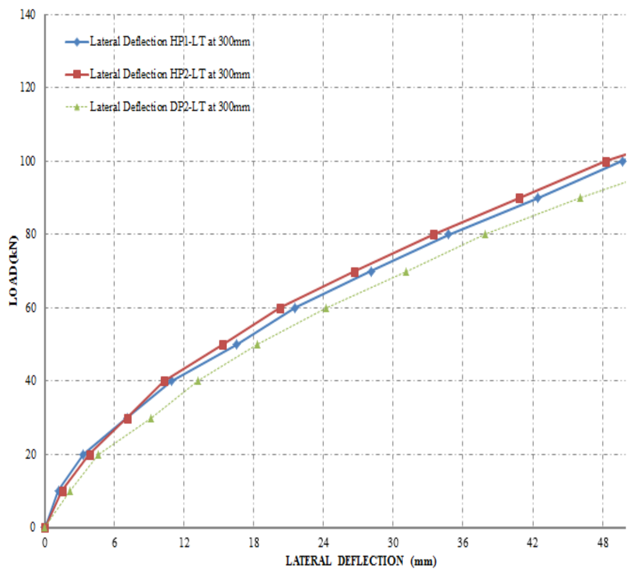

Figure 10: Comparison between long-term lateral resistance of helical piles and long-term lateral resistance of driven piles (Shorter pile group).

It is of interest to note from Figure 10 that the helical pile HP1-LT, HP2-LT and the driven pile DP2-LT have analogous load-deflection curves, especially at the lower levels of lateral deflection. The similarity in the shape of the curves indicates both pile types have the same lateral behavior. The lateral resistance is exclusively controlled by the pile shaft diameter and the embedment depth for both types of piles. The results for this shorter pile group show that the lateral resistance of HP1-LT and HP2-LT was slightly higher than that of DP2-LT. Four years after installation, the lateral capacity of the tested helical piles has recovered well, even better than that of the tested driven pile.

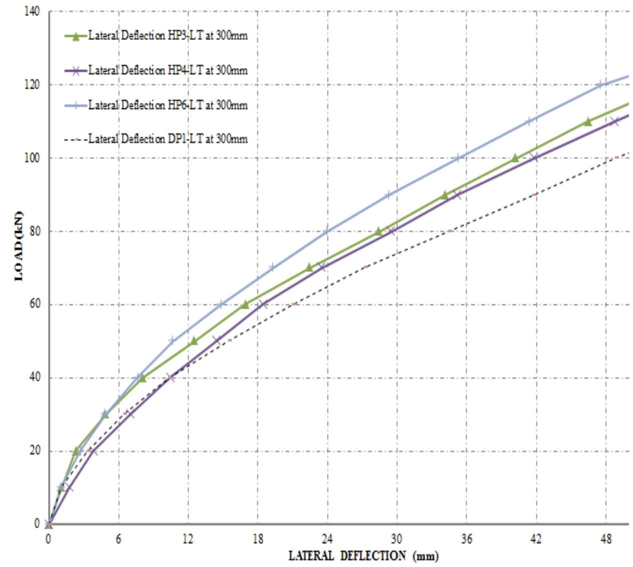

Figure 11: Comparison between long-term lateral resistance of helical piles and long-term lateral resistance of driven piles (Longer pile group).

For the second group results, it is of interest to note from Figure 11 that the lateral resistance of the driven pile DP1-LT was slightly higher than that of the helical pile HP4-LT at lateral deflections less than 12mm. However, in general, the long term test results indicated that the lateral performance of the helical piles was better than that of the driven piles. Similar load-deflection curves were also observed for both pile types. It is believed that installation conditions (weather, machine, workmanship…) can have an important impact on lateral resistance for both pile types.

8 CONCLUSIONS

The following conclusions can be drawn from this study on the long-term lateral resistance of helical piles in cohesive soils.

1. The lateral behavior of helical piles and driven piles was the same, as demonstrated by the nearly identical lateral load-deflection curves for both pile types. This study reconfirmed previous research findings that shaft diameter and embedment depth almost exclusively controls the lateral resistance of both pile types.

2. In comparing the short-term and long-term lateral resistance of helical piles, the long-term test results showed an average increase of 10% to 20%, four years after the pile was installed.

3. The long-term lateral resistance of helical piles showed a considerable recovery over time. The test results indicate that the long-term lateral performance of the test helical piles was equal or even better than that of the test driven piles.

4. The predicted lateral resistance of different piles using LPILE 2012 compared favorably with measured values from field tests performed in this study. It is recommended that the P-Y multiplier method of LPILE be used to estimate long-term and short-term lateral resistance of helical piles.

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