Technical Paper

Title: An Evaluation of Pile Freeze for Driven Piles in Central and Southwest Florida

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An Evaluation Of Pile Freeze For Driven Piles In Central And Southwest Florida

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SYNOPSIS

This paper presents results from three case studies conducted in central and southwest Florida, where dynamic load testing of piles was conducted to quantify pile freeze or set-up. The data from these case studies were subsequently utilized in determining the driving criteria and design load-carrying capacities of piles as part of the overall foundation support system.

For each case study, a 3-stage investigation consisting of: (i) a detailed subsurface investigation and preliminary design of piles; (ii) probe pile driving/monitoring/testing utilizing Pile Driving Analyzer (PDA) supplemented by CAPWAP analyses; and, (iii) final data evaluation was conducted. A total of 12 and 16, 356-mm (14-in.) square precast prestressed concrete (PPC) piles were installed to depths of 15.5 to 20.4 m (51 to 67 ft) and 7.6 to 10.7 m (25 to 36 ft) throughout Sites 1 and 2, respectively. A combination of 254-, 305-, and 356-mm (10-, 12-, 14-in.) square PPC piles (a total of 9 test piles) were installed to depths of 5.6 to 11 m (18.5 to 35 ft) across Site 3. Pile sizes were selected and optimized based on the design loads for each of the respective projects. Longer piles installed at Site 1 exhibited an increase in soil resistance with time (i.e., pile freeze or set-up) ranging from 110 to 400 percent, whereas the shorter piles installed at Sites 2 and 3 exhibited none to 80 percent increase in soil resistance.

Preliminary evaluations confirm that pile freeze or set-up is a viable phenomenon and is more predominant in piles that are driven beyond a threshold depth of 10 to 12 m (30 to 40 ft). Additional case studies are being documented to lend further refinement and credence to these preliminary findings.

INTRODUCTION

A number of investigations have been conducted in the past and are presently ongoing to estimate and quantify the phenomenon of pile freeze (increase in soil resistance with time). It is widely recognized and generally accepted by geotechnical engineers that driven piles exhibit increase in load carrying capacity with time after driving which is a result of soil set-up in certain soil conditions. However, no conclusive pattern of soil set-up has yet been established in any soils for any pile type or size. Observation and documentation of pile capacity increase with time has been facilitated by the advent of dynamic load testing of piles utilizing the Pile Driving Analyzer (PDA). The use of PDA has enabled extensive dynamic testing of piles and in an accurate manner. Dynamic Load Testing (DLT) is much faster and relatively inexpensive when compared with traditional static-load testing because information can be gathered instantly as a pile is driven. Because DLT is faster and cheaper, more piles can be tested to better account for variability in site subsurface conditions. DLT enables better evaluation and prediction of the increase in resistance with time for a single pile (freeze or set-up) or a pile cluster (cluster effect).

Several engineers have documented the increase in pile capacity with time (Schmertmann, 1991) to the extent that this phenomenon of pile capacity increase with time is now routinely being utilized to economically establish pile length and driving criteria. For example, Florida Department of Transportation (FDOT) Standard Specifications for Road and Bridge Construction recommends the evaluation of pile set-up. Beyond case studies provided by different engineers to document this phenomenon, there have been no rigorous studies performed to establish the cause and to predict the magnitude of pile set-up with pile or soil type. Currently, the FDOT in collaboration with the Federal Highway Administration (FHWA) is sponsoring research at the University of Florida intended to shed some light into the causes of set-up with the objective of establishing criteria that can be used to predict the magnitude and rate of pile set-up at the design stage. Until methods for predicting pile set-up are available, engineers are currently evaluating and utilizing pile set on a case-by-case basis. Engineers are finding trends that can be translated from one soil type to the other and some that can not be translated from site to site.

A map identifying the general locations of the 3 case studies discussed herein is presented in Figure 1.

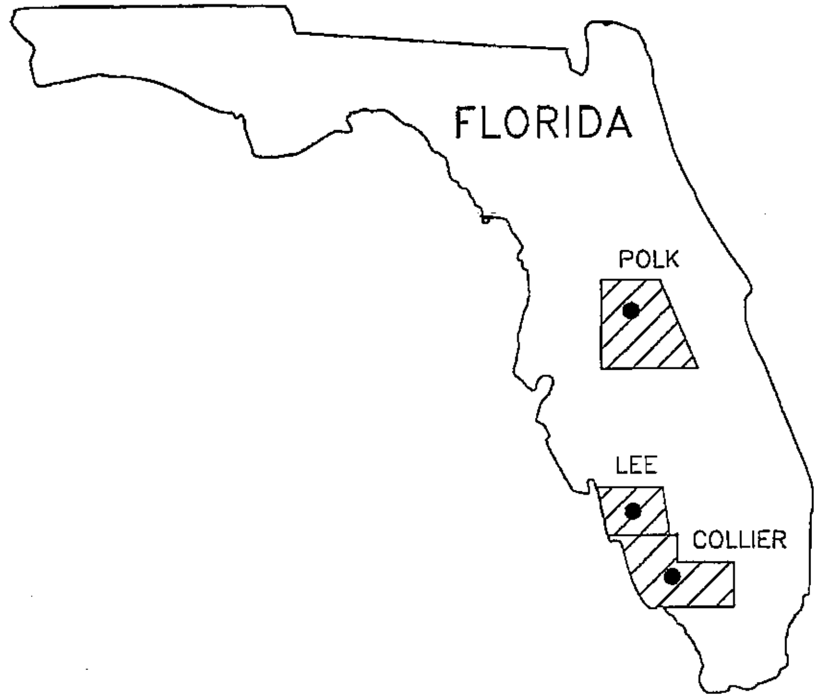

Figure 1. General Location Map of Project Sites

CASE STUDIES

The project sites all lie within Florida. Site 1 is in Collier County in southwest Florida, Site 2 rests in Polk County in central Florida, and Site 3 lies in Lee County also in southwest Florida.

Case 1

The project site is nestled between Estero Bay and the Gulf of Mexico in Fort Myers Beach, Lee County, Florida. The project itself consisted of a 10-story building with parking underneath. Geotechnical exploration at this site included Standard Penetration Tests (SPT) borings and Piezocone Penetration Tests (PCPT) soundings. Generalized subsoil conditions at the site consisted of sands underlain by predominantly marine silty clayey fine sands with intermittent layers of weathered limestone, with N-values ranging from 2 to 20 over a depth of 36.6 m (120 ft). The tidal ground-water table was encountered at approximately 1.2 m (4.0 ft) below the ground surface. Various foundation systems ranging from vibrated concrete columns (VCC) to Interpile were considered. Precast prestressed concrete (PPC) piles were finally selected primarily because of their economy and reliability. Additionally, the ability of DLT with the use of PDA, played a key role to accurately determine specific pile capacity across this site exhibiting variable subsoil conditions. Driving of displacement piles at this site exhibiting varying subsoil conditions proved to be very valuable as this operation assisted in the densification and improvement of the existing marginal subsoils.

Twelve 21.3-m (70-ft) long and 356-mm (14-in.) square PPC probe piles were selected and located throughout the building area for evaluation purposes. Probe piles and production piles were installed using an ICE 520 diesel double acting hammer. This hammer, rated at 4,200 m-kg (30,000 ft-lbs) maximum energy and 22.8 kN (5,070 lbs) ram, was ideal for this type of pile driven in weak subsoil conditions. The hammer stroke adjusted itself depending on soil resistance such that there was no excessive tension stress at the beginning of pile installation when soil resistance is usually low. The hammer stroke increased as the soil resistance increased to provide sufficient energy and force to mobilize the increased resistance.

Test piles were installed to depths ranging from 15.5 to 20.4 m (51 to 67 ft) depending on the location and the capacity obtained at the end of initial driving (EOID). PDA predicted ultimate pile capacity ranging from 73 to 755 kN (8 to 83 tons) at the EOID and from 373 to 1836 kN (37 to 202 tons) at the beginning of restrike (BOR). Time elapsed between BOR and EOID ranged from 18 to 48 hours. Piles at this site exhibited set-up ranging from 113 to 410 percent, where the pile set-up is expressed as a ratio of pile capacity increase over initial pile capacity in percent.

A summary of pile freeze or set-up for Case 1 is presented in Table 1 with a bar graph illustration in Figure 2.

PROBE PILE NO. [1]	PDA CAPACITY AT EOID "a" [2], [4] (kN)	PDA CAPACITY AT BOR "b" [3], [4] (kN)	TIME ELAPSED BETWEEN EOID AND BOR (hrs)	INCREASE [(b-a)/a] x 100 (%)
PP1	181.8	604.5	18	233
PP1A	181.8	681.8	48	275
PP2	454.5	1,236.4	48	172
PP3	509.1	1,836.4	48	261
PP4	754.5	1,763.6	28	134
PP5	136.4	472.7	42	247
PP6	90.9	463.6	42	410
PP7	227.3	909.1	48	300
PP8	254.5	1,027.3	48	100
PP9	81.8	336.4	48	311
PP10	136.4	672.7	18	393
PP10A	136.4	672.7	48	393
PP11	627.3	1,336.4	24	113
PP12	72.7	372.7	18	412
PP12A	72.7	363.6	48	400

NOTES:
[1] some piles tested at multiple time intervals
[2] EOID = end of initial driving
[3] BOR = beginning of restrike
[4] 1kN = 0.11 tons

Table 1. Summary of Pile Set-up (Case 1)

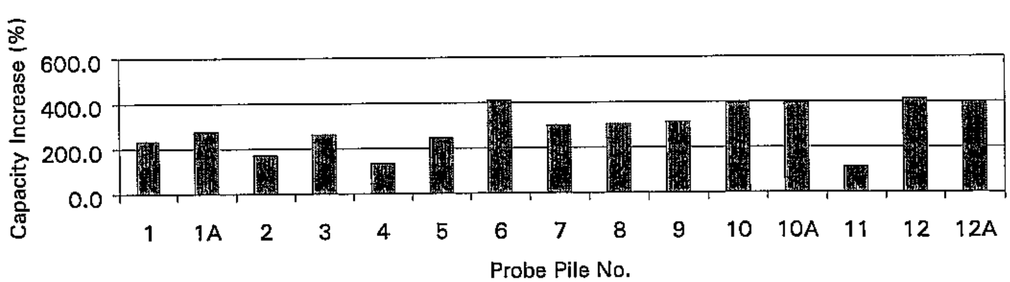

Figure 2. Bar Graph of Pile Capacity Increase (Case 1)

Case 2

This project included an 1,100 ton 3-story printing press foundation for a newspaper publishing facility located in Lakeland, Polk County, Florida. This printing press foundation had very stringent criteria for allowable and differential settlement as well as loading conditions that were dynamic in nature. The subsoil conditions at this site consisted of a shallow cemented layer underlain by silty clayey fine sands with N-values ranging from 10 to 25 in the upper 3.1 m (10 ft) and between 10 to 25 from 3.1 to 9.3 m (10 feet to 30 ft) below ground surface. A perched ground-water table was encountered at depths ranging from 1.5 to 3.1 m (5 to 10 ft) below the existing ground surface. While a majority of structural elements for this project were supported on shallow foundations, the vibratory press with the 3-story high mechanical equipment was supported on PPC piles.

Twenty-one 13.8-m (45-ft) long, 356-mm (14-in.) square PPC probe piles were installed and tested in the press area and the adjoining column line. Probe and production piles were installed by a VULCAN 08 air steam hammer. This hammer was rated with maximum energy of 2,100 m-kg (15,000 ft-lb) and a ram weight of 36 kN (8,000 lbs). Due to the presence of a shallow hard pan layer, most of the production piles heaved.

Probe piles were installed to the depths ranging from 7.6 to 12.2 m (25 to 40 ft) below the existing ground surface. PDA-predicted ultimate pile capacity ranged from 736 to 2,186 kN (81 to 240 tons) at EOID and from 814 to 2,596 kN (90 to 286 tons) at BOR. Time elapsed between EOID and BOR ranged from 24 to 48 hours. Piles at this site exhibited set-up ranging from none to 36 percent.

A summary of pile set-up for Case 2 is presented in Table 2 with a bar graph illustration in Figure 3.

PROBE PILE NO.	PDA CAPACITY AT EOID "a" [1], [3] (kN)	PDA CAPACITY AT BOR "b" [2], [3] (kN)	TIME ELAPSED BETWEEN EOID AND BOR (hrs)	INCREASE [(b-a)/a] x 100 (%)
PP1	922.7	959.1	48	4
PP2	972.7	909.1	48	-7
PP3	822.7	900.0	48	9
PP4	736.4	1,004.5	24	36
PP5	909.1	918.2	24	1
PP6	790.9	877.3	48	11
PP7	2,186.4	2,595.5	24	19
PP8	909.1	959.1	24	6
PP9	763.6	813.6	48	7
PP10	945.5	1,481.8	24	57
PP11	950.0	922.7	24	-3
PP12	854.5	1,031.8	48	21
PP13	995.5	1,231.8	24	24
PP14	909.1	854.5	24	-6
PP15	854.5	995.5	48	16
PP16	918.2	N/A	48	N/A

NOTES: [1] EOID = end of initial driving
[2] BOR = beginning of restrike
[3] 1 kN = 0.11 tons

Table 2. Summary of Pile Set-up (Case 2)

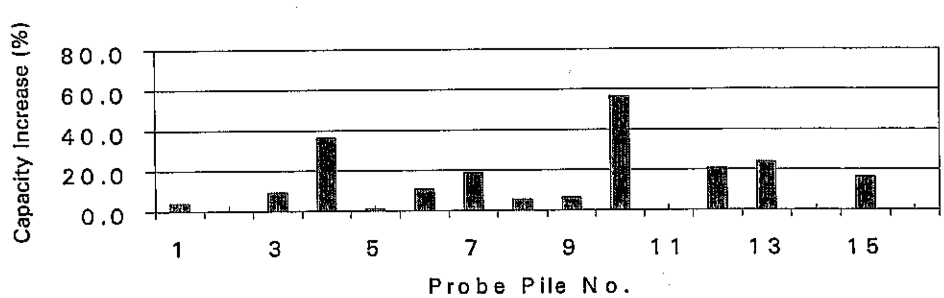

Figure 3. Bar Graph of Pile Capacity Increase (Case 2)

__Case 3__

This project consisted of a dry-boat storage facility located in Bonita Springs off Little Hickory Bay in Collier County, Florida. The subsoil conditions at the project site consisted of very loose to loose fine sands with silt to poorly-graded fine sands, with N-values ranging from 2 to 14. A shallow weathered and fractured limestone layer existed at some locations with N-values ranging from 30 to 50. The tidal ground-water table was encountered at a depth ranging from ground surface to 0.9 m (3 ft) below existing ground surface. PPC piles were chosen over other types of deep foundation systems because of their ability to densify the existing marginal subsoils (it is interesting to note that augered cast-in-place piles were utilized at a nearby site and installed to depths ranging from 24.2 to 30.5 m (80 to 100 ft)).

Nine 7.6- to 12.2-m (25- to 40-ft) long, 254- to 356-mm (10- to 14-in.) square PPC were installed and tested at this site using the PDA. Probe piles and production piles were installed using an ICE 180 diesel double-acting hammer with a maximum energy rating of 1,120 m-kg (8,100 ft-lbs).

Probe piles were installed to depths ranging from 6.4 to 11 m (21 to 36 ft). PDA predicted ultimate pile capacity ranged from 127 to 568 kN (14 to 63 tons) at the EOID and 272 to 605 kN (30 to 67 tons) at the BOR. Time elapsed between EOID and BOR ranged from 4 hours to 24 hours. Piles at this site exhibited set-up ranging from 6 to 114 percent.

A summary of pile set-up for Case 3 is presented in Table 3 with a bar graph illustration in Figure 4.

PROBE PILE NO.	PDA CAPACITY AT EOID "a" (1), (3) (kN)	PDA CAPACITY AT BOR "b" (2), (3) (kN)	TIME ELAPSED BETWEEN EOID AND BOR (hrs)	INCREASE [(b-a)/a] x 100 (%)
PP1	254.5	377.3	4	48
PP2	395.5	422.7	4	7
PP3	177.3	272.7	24	54
PP4	568.2	604.5	24	6
PP5	286.4	318.2	24	11
PP6	181.8	290.9	24	60
PP7	127.3	272.7	8	114
PP8	209.1	309.1	7	48
PP9	240.9	336.4	5	40

NOTES:
(1) EOID = end of initial driving
(2) BOR = beginning of restrike
(3) 1 kN = 0.11 tons

Table 3. Summary of Pile Set-up (Case 3)

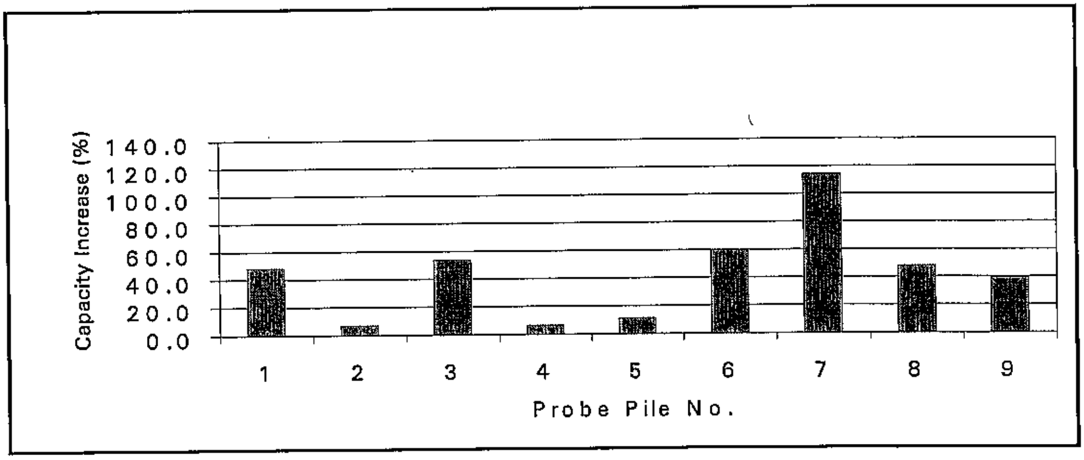

Figure 4. Bar Graph of Pile Capacity Increase (Case 3)

OBSERVATIONS AND CONCLUSIONS

Based on test results from the 3 case studies discussed herein, the following observations and conclusions can be drawn.

1. Longer piles at Site 1 exhibited high set-up than shorter length piles at Sites 2 and 3. This trend can be attributed to the fact that pile set-up is predominantly derived from skin friction rather than end bearing. Longer piles naturally have greater surface area versus shorter piles of the same diameter.

2. Pile set-up is directly proportional to the confining pressure of the soil. Longer piles exhibit higher confining pressures due to the overburden. This phenomenon has been reported by others (Rwebyogo, 1987; Schmertmann, 1991).

3. Further studies involving comparison of CAPWAP-predicted pile capacities at the EOID and BOR will give insight as to whether the phenomenon of pile set-up is predominantly contributed from the skin friction portion of the pile capacity versus the end bearing portion. Additionally, if pile set-up is

greater at a deeper depth than at a shallower depth assuming the soil type and strength is not significantly different with depth

4. Optimization of pile penetration depths based on a dynamic load testing program utilizing PDA was achieved for the case studies discussed herein.

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The case history information from these projects provides a useful database for reference on future projects of this type in Florida and elsewhere.

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