THE USE OF SPIN FIN® PILES IN MASSACHUSETTS

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Driven pipe piles are commonly used for near and offshore structures due to their omni-directional bending resistance, large surface area, and ease of installation. However, these piles typically cannot be driven deep enough to develop significant and sustained uplift capacity, and in some cases do not generate enough end-bearing resistance before being overstressed during driving. When driven closed-ended, their relatively light weight to cross-sectional ratio, and when driven open-ended their tendency to prematurely plug, are some installation short comings. Spin Fin® piles are traditional pipe piles fitted with flat, steel plates ("fins") attached at a slight angle over the lower few feet of the pipe. Their design development dates back several decades for projects associated with harsh, limited weather window, offshore Alaskan oil field work. These projects required a pile type that could generate high and sustained capacity in both compression and tension, at relatively shallow depth. During pile driving, a relatively short, high capacity pile translates into more rapid installations with smaller and more efficient equipment. In this type of environment, where pile capacities are large, cyclic loading is typical, and relatively high pile movement is tolerable, the Spin Fin® pile is a superior solution. This paper describes the experience of using Spin Fin® piles on several recently completed Massachusetts Steam Ship Authority projects.

INTRODUCTION

Near and offshore structures such as dolphins, piers, moorings, and wind turbines are subject to severe and cyclic loading conditions. Lateral loads are converted to axial tension and compression loads through use of a combination of plumb and batter pile configurations. At elevated capacities, traditional pipe pile drivability often comes into question. Significant pile tensile capacity, which usually drives hammer energy and selection, often requires a much deeper pile penetration than similar compression capacity, resulting in a dilemma of hammer to pile incompatibility. In many cases, this would necessitate using a significantly larger pile section than structurally required.

Spin Fin® piles are traditional pipe piles fitted with flat, steel plates ("fins") attached at a slight angle over the lower few feet of the pipe. The geometry of the fins is such that when viewed from but to tip, the top of one fin meets the bottom of the adjacent fin, thus providing 360 degree coverage. Refer to Figure 1 for a photograph showing a typical Steam Ship Authority project Spin Fin® pile. The angled "fins" cause the pile to rotate slightly as it is driven into the soil profile. When connected to the pile cap, the "fins" lock in place and act as an anchor, thereby significantly increasing the uplift capacity compared to a pipe alone. The "fins" also increase the gross bearing area at the bottom of the pile and improve the end bearing capacity.

Figure 1. Typical Spin Fin® pile.

As a result, the compression and tensile capacity for Spin Fin® piles is usually achieved at shallow depths compared to similarly sized straight pipe piles. The development of this high capacity is deceiving, as it is not realized until the fins are locked into place at the completion of the cap construction. This requires special arrangements when load testing, such as torque preventing connections of the pile head in the load frame. Because this "post-construction" connection condition is necessary for the development of tensile capacity and large deformations are required to take advantage of both compression and tensile capacity, dynamic load testing under-predicts the actual pile capacity, particularly with regard to uplift. Research has shown that when subject to cyclic loading, Spin Fin® pile capacity does not degrade as would be anticipated for a straight pipe pile (Campbell, et. al., 1987). Therefore, determination of the final tip elevation and capacity requires experience with Spin Fin® behavior in addition to knowledge of subsurface conditions, pile driving observations, and pile load tests and analyses.

Spin Fin® piles are used for support of offshore structures in other parts of the U.S., particularly along the west coast. The Massachusetts Steam Ship Authority has recently used the Spin Fin® piles in three of their major terminals reconstruction projects in Oak Bluffs, Hyannis, and Nantucket, Massachusetts. The first project in Oak Bluffs involved an intricate, unusual, and highly instrumented test program that included test pile driving and compression, tension, and cyclic load testing of both Spin Fin® and traditional straight pipe piles. Dynamic load testing was also performed on the test piles, as well as several indicator piles, to evaluate drivability and for capacity correlation-comparison purposes.

OAK BLUFFS TEST PROGRAM

As part of the $18,000,000 ferry terminal reconstruction project in Oak bluffs, Massachusetts, a pre-construction phase test program was performed on several Spin Fin® and straight pipe piles (Hart and Chernauskas, 2008a, Hart and Chernauskas, 2008b, Nacci, 2008). The test program involved:

1. Multiple staged compression, tension and/or cyclic load tests on instrumented 20-inch and 16-inch diameter Spin Fin test piles.
2. Fabrication of a load frame that included both 16-inch diameter straight pipe and Spin Fin piles for support/resistance during testing of the two test piles. One of the Spin Fin frame support piles and one of the straight pipe frame support piles were instrumented so that load-displacement data could simultaneously be obtained during testing of the two Spin Fin test piles. Refer to Figure 2 for a photograph of the load test frame.
3. Four 16-inch diameter close-end straight pipe indicator piles were driven around the site to assess drivability.
4. Dynamic testing was performed on all test, frame support, and indicator piles using an ICE I-30 hammer.

Figure 2. Load Test Frame.

The objective of the load test program was to:

1. Evaluate the load-deflection behavior in compression and/or tension for the two instrumented Spin Fin test piles. In addition, further load-deflection behavior was obtained on the two instrumented frame support piles. These instrumented frame support piles enabled comparison of the performance of the Spin Fin versus the straight pipe.
2. Drivability of the Spin Fin and straight pipe using a conventionally available hammer (ICE I-30).

3. The use of the dynamic testing to evaluate hammer performance and pile drivability, assess straight pipe capacity, for correlation/calibration with Spin Fin compression capacity, and comparing compression capacity between Spin Fin and straight pipe.

TEST PROGRAM RESULTS

A summary of the load test program findings is described below:

1. The 20-inch Spin Fin compression capacity well exceeded 550 kips at a penetration of 70 feet below mudline. Based on strain gage data, around 65% of the compression capacity was developed in end bearing and friction around the fins.
2. The 20-inch Spin Fin tension load-displacement results did not exhibit a "plunging" failure up to an applied load of 500 kips. As the load increased, the displacement increased. This behavior is a result of the Fins engaging the soil cone above the fins. Based on strain gage data, the 6 foot fin section increased the tension capacity by approximately 75% over the 64 foot straight pipe portion above the fins.
3. The 16-inch Spin Fin compression capacity was around 230 kips at a penetration of 25 to 35 feet below mudline. Static-cyclic testing indicated a compression capacity of around 270 kips. Based on strain gage data, around 75% of the compression capacity was developed in end bearing and friction around the fins.
4. The 16-inch Spin Fin tension capacity was around 140 kips at a penetration of 35 feet below mudline. Based on strain gage data, the 5 foot fin section increased the tension capacity by approximately 130% over the 30 foot straight pipe portion above the fins.
5. Due to the ability of the fins to engage the cone of soil above the fins (for tension) and the increased effective end bearing area the fins create (for compression), Spin Fin piles can tolerate much larger deflections than traditional pipe piles. This performance works well for offshore marine foundations.

The results of the test program are presented in Figures 3 through 7 and Table 1.

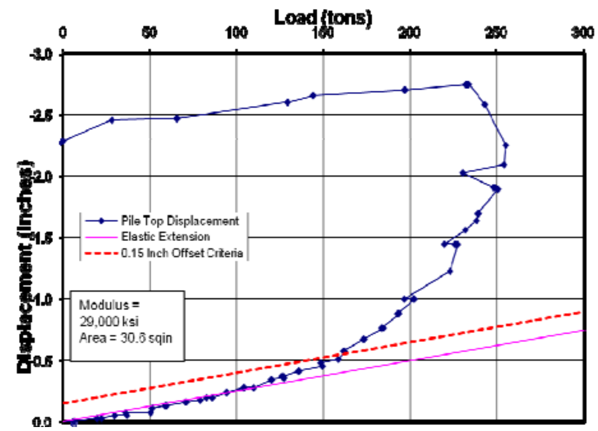

Figure 3. 20-inch Diameter Spin Fin Tension Test Results

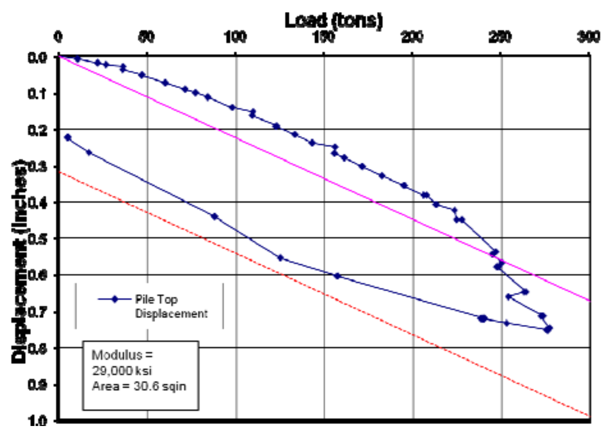

Figure 4. 20-inch Diameter Spin Fin Compression Test Results

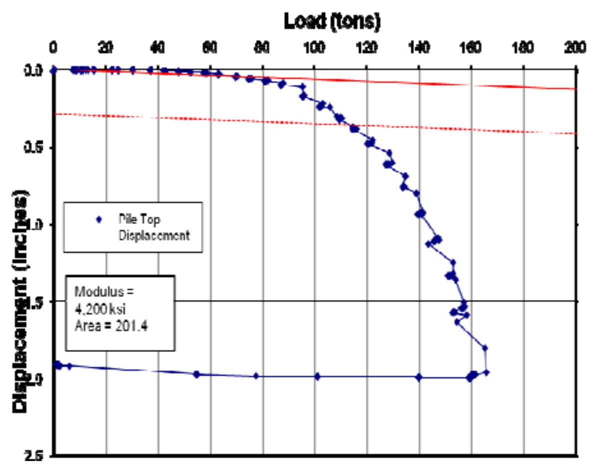

Figure 5. 16-inch Diameter Spin Fin Compression Test Results

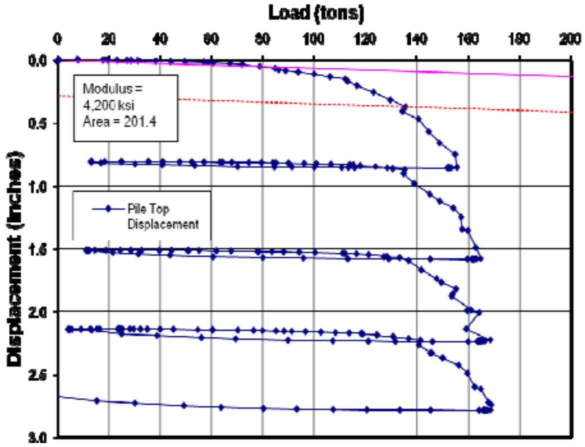

Figure 6. 16-inch Diameter Spin Fin Static Cyclic Compression Test Results

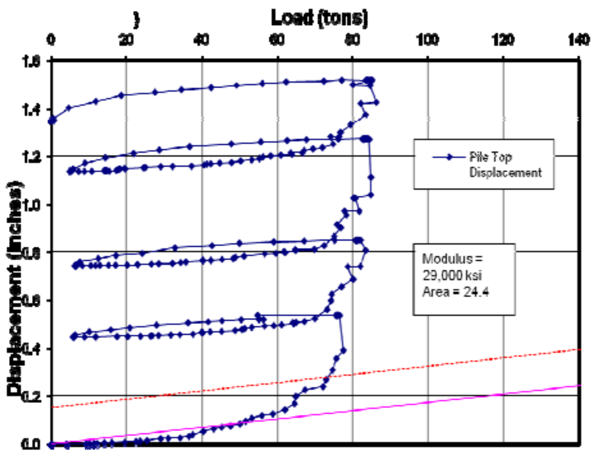

Figure 7. 16-inch Diameter Spin Fin Static Cyclic Tension Test Results

SPIN FIN® PERFORMANCE AND OBSERVATIONS

In all the three project locations where the Spin Fin piles were used, the soils were primarily loose to medium dense sands in the shallower depths and dense at deeper depths. At the Oak Bluffs Terminal, the soil did not become dense until a depth of around 60 feet below mudline. The design philosophy for the deck and wharf structures involved driving the 16" Spin Fin piles to a shallow depth of 25 feet for a compression design load of 50 tons and to 35 feet for a tension design load of 30 tons. The pipe piles required penetrations greater than 50 feet to obtain similar results. The closed ended 16-inch pipe could not be driven deeper than approximately 70 feet with the I-30 hammer. When the plate was removed, the 16-inch open ended pipe could be driven a little deeper to around 80 feet below mudline. For the dolphin structures, the design philosophy involved driving the 20 inch Spin Fin piles to a depth of 70 feet below mudline to develop compression and tension design loads of 130 tons and 85 tons, respectively. Greater depths would have

Table 1. Summary of Dynamic and Static Load Testing Results

Pile Type	Depth below mudline (feet)	Blow Count (blows/in)	Compression Capacity (kips)			Tension Capacity (kips)		
			Dynamic Testing	Static	Static Cyclic	Dynamic Testing	Static	Static Cyclic
16"OEP Pipe	50	1 to 2	200 to 230			190		
16"OEP Pipe	70 to 80	6 to 9	~550 to ~650	>>260		170 to 250	>>160	
16"CEP Pipe	50	1-1/2 to 2	270 to 310			110 to 125		
16"CEP Pipe	60 to 70	10 to 30	~500 to ~550					
16"CEP SF	25	1 to 2	250 to 310	220	270	50 to 75		
16"CEP SF	35	1 to 2	260	240		110	120 to 160	140
20"OEP SF	70	7 to 8	560	>>550		260	>>320	

been necessary for straight 20-inch pipe piles. The installation of the Spin Fin piles to the shallower depths enabled the use of the smaller I-30 hammer and significantly reduced the installation costs. Figure 8 presents a photograph showing the installation of the 16-inch Spin Fins for the wharf structures. Figure 9 shows the overall completed pier facility at the Oak Bluffs terminal. Note the turning dolphin in the front of the ferry.

Figure 8. Installation of 16-inch Spin Fin piles at the Oak Bluffs Terminal.

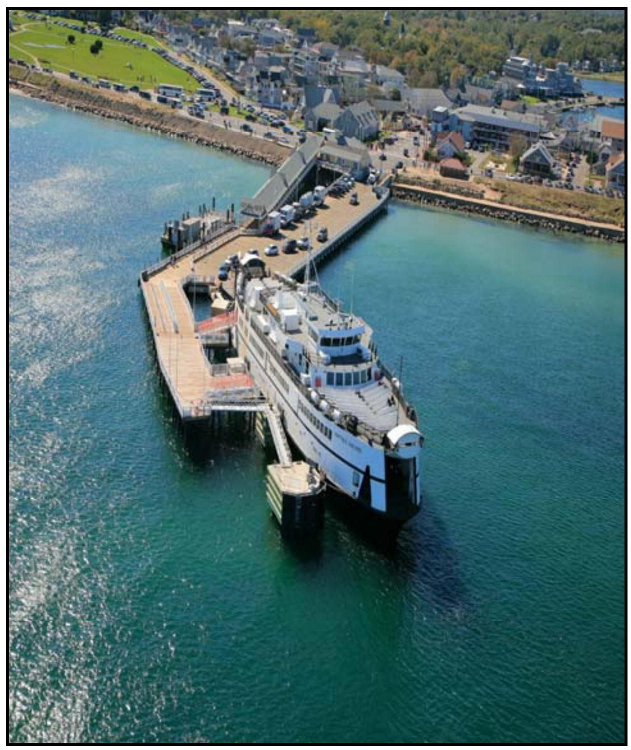

Figure 9. Completed Pier Facility at the Oak Bluffs Terminal.

At the Hyannis Terminal, 16-inch Spin Fin piles were used for all dolphin structures in the new Slip 2 berth. The sands at the Hyannis site were medium dense for depths of around 100 feet below mudline. The Spin Fin piles were driven to a depth of 35 feet below mudline to develop a compression design load of 55 tons and a tension design of 30 tons. Past dolphin structures for the immediately adjacent Slip 1 berth were supported on straight pipe piles driven to depths of 120 feet to obtain similar design loads and the use of the Spin Fins reduced potential pile lengths by over 50%. Figure 10 presents a photograph showing the 16-inch Spin Fins for a dolphin structure. Figure 11 shows the overall completed pier facility at the Hyannis Terminal.

At the Nantucket Terminal, 20-inch Spin Fin piles were used for several replacement dolphin structures. The sands at the Hyannis site were medium dense for depths of around 100 feet below mudline The Spin Fin piles were driven to a depth of 80 feet below mudline to develop a compression design load of 90 tons and a tension design of 50 tons. A short time after the replacement dolphins were completed, one of the ferries impacted the head dolphin at speeds much greater than used in the design. The Spin Fin piles experienced large displacements under the impact, where most of the movement was elastic. The damage to the dolphin was significant enough to require repair. The Spin fin piles performed well and were reused in the repaired dolphin without modification.

CONCLUSIONS

Spin Fin piles are ideal where relatively large pile deformations are acceptable in the pile design. When traditional straight pipe requires penetrations on the order of fifteen to twenty feet more than the corresponding Spin Fin piles, the Spin fins piles begin to become cost effective. This is especially true if splicing is avoided. For the

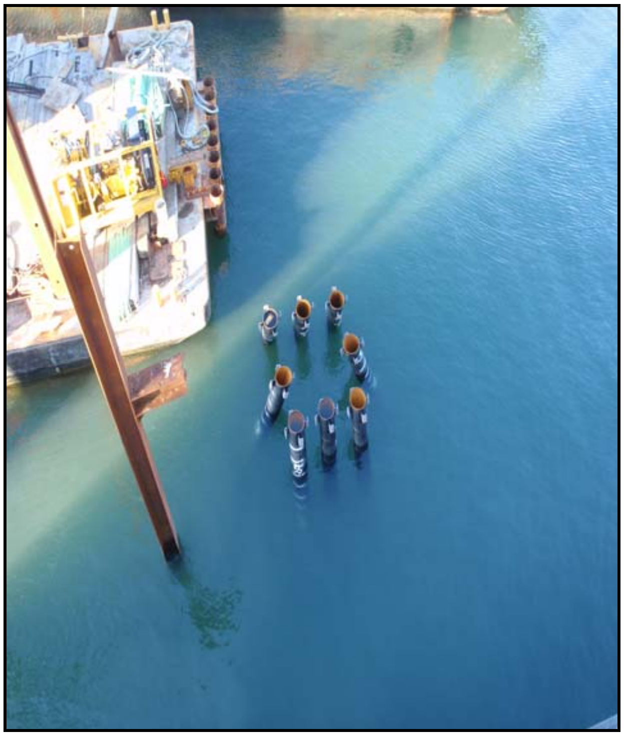

Figure 10. 16-inch Spin Fin piles for a dolphin structure at Hyannis Terminal.

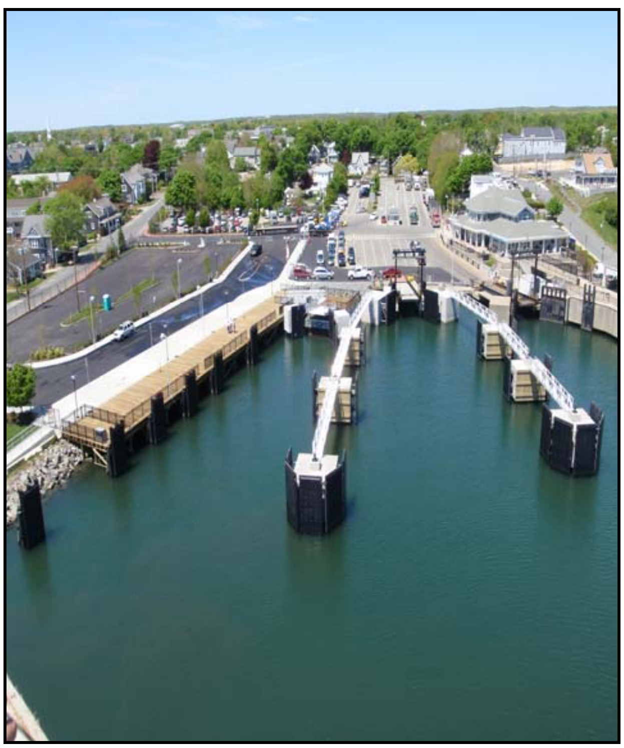

Figure 11. Completed Pier Facility at the Hyannis Terminal.

sites mentioned above, the subsurface conditions consist of relatively looser sands overlying deeper dense sands. The Spin fin piles could be installed within the shallower looser sand layers where traditional straight pipe piles could not develop the required capacities.

At the Oak Bluffs and Hyannis Terminals, the use of the Spin Fin piles significantly reduced pile lengths and saved over $1,000,000 in installation costs The Oak Bluffs test program has provided an experience base for future Steamship Authority projects where offshore and/or pier facility structures are planned. In addition, the shorter pile penetrations eliminated the need for splicing, which reduced overall installation times and schedules. This allowed the Hyannis project to be completed in one off season in stead of three off seasons as originally planned. At the Nantucket Terminal, the approach dolphins performed well under extreme load conditions due to the ability of the Spin Fin piles to undergo significant displacement without failing during an unanticipated, relatively high speed, ferry impact.

ACKNOWLEDGEMENTS

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