Technical Paper

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Design And Construction Of Pile Foundations For A Building Complex – A Case History

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SYNOPSIS

This paper presents a case history of design and effective utilization of pile foundations for Waterside at Bay Beach Condominiums located in Fort Myers Beach in southwest Florida, USA. A building complex consisting of a total of 8, 10-story buildings (with 1-story parking underneath) along with recreational facilities (such as pool and tennis courts) has been planned for final construction. Following an evaluation of various foundation alternatives and site-specific constraints, a precast prestressed concrete (PPC) pile-supported system was selected. The first phase of the project consisted of construction of Building No. 1 and this paper presents various design aspects and methodologies utilized in choosing and optimizing the foundation system.

The building foundations were designed for a pile capacity of 353 kN (40 tons) in compression, 13 kN (1.5 tons) in lateral capacity for a deflection of 0.64 cm (0.25 in) and 133 kN (15 tons) in uplift capacity. The axial and lateral allowable pile capacity and lengths were predicted using SPT94 and LPILE computer programs, which are generally used in Florida, USA. As part of the design process, an extensive probe pile driving program was carried out in order to evaluate the pile driving equipment, determine and verify pile capacities, and optimize the production pile lengths. A total of 12, 356 mm (14-in) square, PPC concrete piles were driven and dynamically load tested utilizing Pile Driving Analyzer (PDA) within the building limits as part of the probe pile driving program. Utilization of PDA during probe pile driving helped in predicting pile freeze (i.e., increase in pile resistance with time) and thus optimized the production pile lengths. This information was effectively utilized as part of the overall quality control program to install a total of 559 PPC piles (including 12 probe piles) within building 1 at the project site to depths ranging from 13 to 20 m (42 to 68 ft) below existing ground elevation as part of foundation support system. Prior to installation of probe or production piles, a termination criterion was established using 1-dimensional wave equation analyses in addition to the design pile embedment requirement. The predicted pile capacities compared very well with the capacities from the CAPWAP analyses for probe piles.

This engineered, monitored and tested foundation solution provided an effective and satisfactory basis for completion and approval of the foundation work for Waterside Building No.1. Building has since been occupied and a recent reconnaissance has indicated that the building foundations are performing satisfactorily. Furthermore, construction of two more buildings is currently underway.

INTRODUCTION

The Waterside Resort Complex is nestled between Estero Bay and Gulf of Mexico providing a secure, gated beachfront community in southwest Fort Myers, Florida, U.S.A. The building project consists of a 10-story tower with parking underneath and an extended parkade along one of the wings. The tower is of concrete and masonry construction with post-tensioned floor slabs. The geotechnical design was completed in May 1995, construction commenced in February 1996 and the building was released for occupancy in April 1997. A project building layout and boring location plan is illustrated in Figure 1.

The purpose of the value engineering services provided by ASC for the project included: (i) performing a complete geotechnical exploration, testing, and engineering evaluation program; (ii) dynamically load testing probe piles utilizing PDA; (iii) assisting the owner in the proper selection of an economical, effective, and satisfactory foundation system; and, (iv) providing pile installation logging and quality control inspection/testing services during the foundation construction phase of the overall construction.

SUBSURFACE CONDITIONS AND PROJECT DATA

Pre-construction project site features included a generally level topography with jurisdictional wetlands along the north property line. The location of all borings completed in 1995 are indicated in Figure 1.

A detailed geotechnical exploration program was undertaken, consisting of Standard Penetration Test (SPT) borings and Piezocone Penetration Test (PCPT) soundings. The work was carried out using conventional drilling and sampling techniques.

In general, the project site stratigraphy consisted of very loose to medium dense poorly graded sands to silty sands to approximately 8.2 to 9.8 m (27 to 32 ft). This strata is underlain by medium dense to very loose weathered limestone to depths of 9.8 to 14.6 m (32 to 48 ft) and overlays sands to silty sands as well as clayey and gravelly sands to depths of 13.1 to 25 m (43 to 82 ft). Stiff to very stiff sandy clays to the termination depth of 37.5 m (120 ft). A generalized subsurface profile, compiled from 6 SPT borings and 4 PCPT soundings to depths ranging from 18 to 36 m (60 to 120 ft) was utilized.

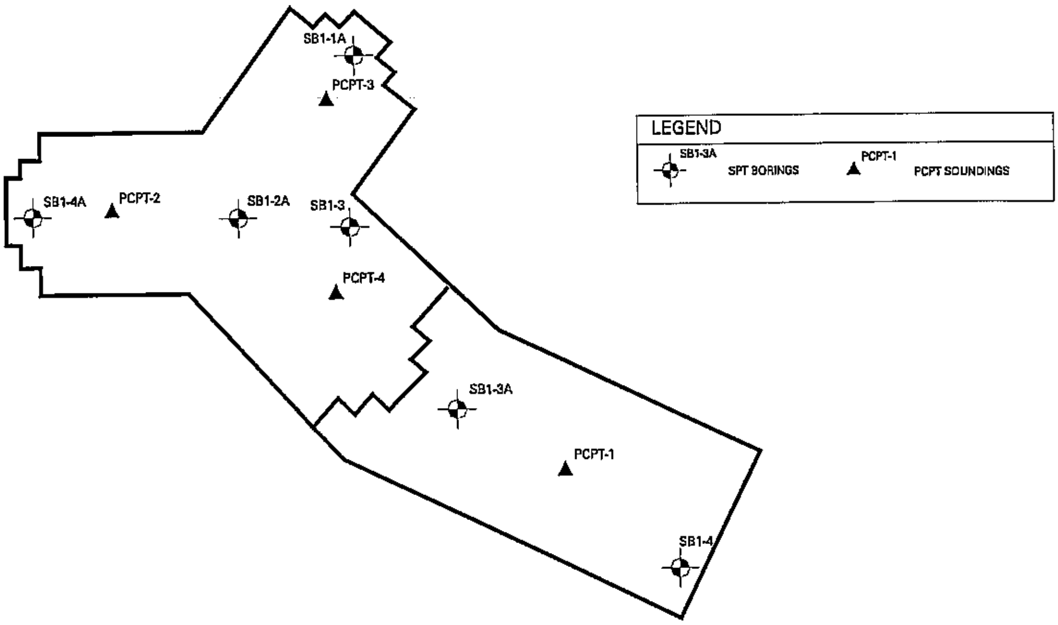


Figure 1. Building Layout and Boring Location Plan

FOUNDATION DESIGN AND ALTERNATIVES

The first step of the design process was to evaluate various foundation systems and associated costs. Several foundation alternatives were considered for the proposed tower structure including: (i) driven precast prestressed concrete (PPC) displacement piling; (ii) cast-in-place auger piles; (iii) Interpile; (iv) Vibrated Concrete Columns (VCC) pile; (v) ground modification using vibro-replacement technique; and (vi) monotube steel pipe with tapered fluted sections. In view of the owner's accelerated construction schedule and the mandated timeframe, a driven prestressed concrete piling system was finally selected for the tower and connected parkade structure. Piles were designed to penetrate through the weathered limestone layer as composite action piles.

The allowable capacity of piles were estimated using SPT94 software. This program, which was developed and used by the Florida Department of Transportation, estimates the axial capacity of a pile based on SPT "N" values. The design method used in SPT94 has been found to be very accurate for driven piles in cohesionless soils (ref 3). Results indicated that prestressed concrete piles driven into silty sand, clayey sand, weathered limestone and sandy lean clays to depths ranging from 12 to 21 m (40 to 70 ft) below the original ground surface will provide a satisfactory and economical foundation alternative.

PROBE PILE AND DYNAMIC LOAD TESTING (DLT)

In an effort to optimize penetration and capacity requirements for piles a DLT program utilizing PDA instrumentation was recommended and performed.

Dynamic Load Testing

Twelve 21.3 m (70 ft) long and 356 mm (14 in.) square PPC probe piles were dynamically load tested during the probe pile driving and testing program within the tower and garage area. The purpose of the probe pile program was to evaluate the suitability of the contractor's pile driving equipment, determine and verify pile capacities, provide production pile lengths, and establish driving criteria for use during the production pile driving phase of the project.

The PDA was utilized for this site to better evaluate and predict the increase in pile resistance with time (i.e., set-up or freeze). This benefit was incorporated in the determination of production pile lengths.

Three probe piles were instrumented over their entire lengths, while the remaining probe piles were instrumented after 9 to 15 m (30 to 50 ft) of driving. Additionally, all probe piles were instrumented during restrikes. A total of 12 piles were installed and tested. Restrike of all 12 probe piles was performed after approximately 1 to 2 days. Probe piles were driven to depths ranging from 51 to 66 ft. In view of the developer's desire to use these probe piles within the final structure, an attempt was intentionally made not to drive them the entire length in order to leave adequate allowance for cut-off and PDA gage installation.

Dynamic load tests on probe piles confirmed that the subsoil conditions at the project site were highly variable, thus making the site ideally-suited for dynamic load testing utilizing a PDA since it was the most appropriate testing method to account for such variability. Because it being relatively inexpensive and quick, many tests were performed to provide an interpretation of a larger portion of the site. Alternately, 12 static-load tests would have been required to obtain the quality and quantity of useful information as obtained during dynamic load tests utilizing the PDA.

PDA predicted ultimate pile capacity ranged from 69 to 715 kN (8 to 83 tons) at the end of initial driving (EOID) and from 320 to 1750 kN (37 to 202 tons) at the beginning of restrike (BOR). Time elapsed between BOR and EOID ranged from 18 to 47 hours. Piles at this site exhibited set-up ranging from 113 to 410 percent. The pile set-up is expressed as a ratio of pile capacity increase over initial pile capacity in percent. A summary of PDA results is tabulated in Table 1.

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. Pile Freeze or Set-Up

Results of CAPWAP Analyses

Dynamic data obtained in the field was further analyzed according to Case Pile Wave Analysis Program (CAPWAP) for a more comprehensive understanding of the soil and pile behavior during pile driving (ref 2). CAPWAP analyses were performed on a total of 15 blows collected during restrikes of probe piles. These analyses provided a better evaluation of total ultimate pile capacity. It is a signal-matching process where a measured signal is matched with a simulated signal. This step provides a refinement of the pile capacity estimated in the field during driving. Additionally, CAPWAP provided a distribution of soil resistance along the embedded pile depth. The distribution of resistance along the pile depth enabled an estimation of resistance at other depths above the pile tip (this type of information is difficult to obtain using conventional static-load test unless expensive instrumentation such as telltales are installed in the test pile prior to driving). Results from CAPWAP analyses including static pile capacity, soil resistance distribution along pile shaft and under toe, soil damping and quake (maximum elastic deformation) values, and forces along pile length at ultimate resistance are presented in Table 2.

PROBE PILE NO.	EMBEDMENT DEPTH (m)	BLOW COUNT (bpi)	PDA CAPACITY (kN)	CAPWAP CAPACITY (kN)			QUAKE (Q) AND DAMPING (J)			
				SIDE FRICTION	END BEARING	TOTAL	Q_s	Q_t	J_s	J_t
PP1	19.7	6	605	477	102	579	.05	.240	.425	.075
PP1A	19.7	6	700	600	93	693	.041	.200	.207	.195
PP2	19.7	10	1132	933	405	1338	.041	.132	.577	.550
PP3	18.8	18	1823	1516	325	1842	.114	.080	.727	.742
PP4	18.8	10	1764	1205	367	1573	.092	.153	.724	.289
PP5	18.9	4	468	369	117	486	.030	.285	.205	.025
PP6	19.7	4	436	280	121	401	.039	.226	.161	.080
PP7	15.2	5	827	695	215	911	.087	.220	.433	.287
PP8	19.7	16	982	953	35	988	.086	.119	.591	.335
PP9	17.6	4	336	314	75	388	.039	.430	.199	.014
PP10	19.7	4	673	6500	6	656	.049	.416	.165	.131
PP10A	19.8	5	614	566	92	658	.070	.236	.309	.125
PP11	18.8	16	1295	923	441	1364	.065	.157	.523	.319
PP12	20.0	4	364	396	46	443	.050	.200	.053	.043
PP12A	20.1	3	364	323	61	384	.035	.190	.117	.056

Table 2. Summary of CAPWAP Results

Production Pile Lengths

Following completion of the probe pile and DLT program specific pile lengths and capacity were finalized after taking into consideration the excavated and prepared surface elevations of various areas within the building limits. PDA assisted DLT program resulted in a fully optimized pile layout plan utilizing 10 different pile lengths throughout the tower and parkade area. Allowable capacities ranged from 120 kN (27 tons) to 355 kN (40 tons).

Pile Installation and Quality Control

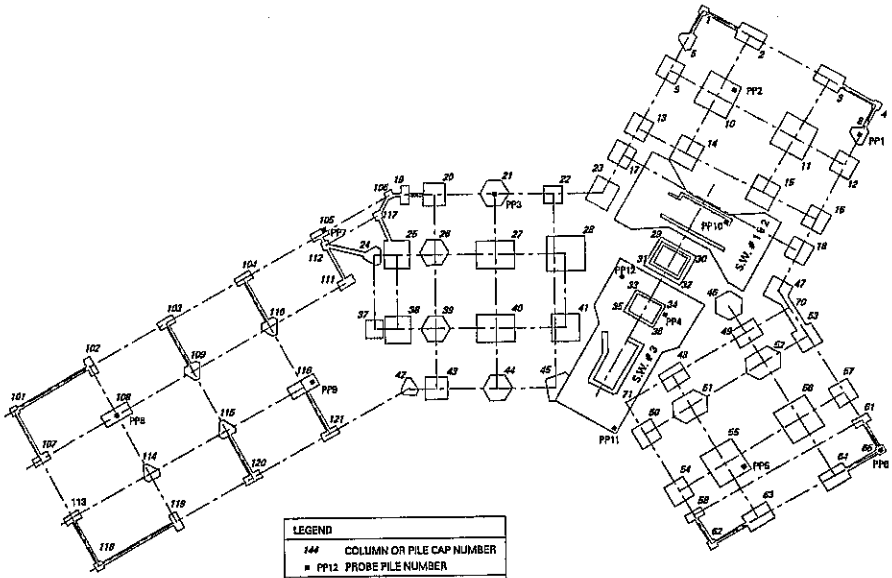
Following the geotechnical consultant's review of the pile layout plan, details of pile driving specifications were finalized for the production pile program to proceed. Work commenced following completion of the prepared (i.e., excavated and graded) soil surface, and full-time monitoring and logging of the program was provided. Records of pile number, location, date of installation, length of pile, blows per foot, hammer energy, and unusual occurrences for each pile were kept. The approval for the pile driving termination was given upon review of pile driving records by an ASC engineering representative.

A total of 559 PPC piles were installed during probe and production pile installation phase. For the tower area, 356 mm (14 in.) square piles were delivered to the site in the lengths of 13.7 m (45 ft) to 21.4 m (70 ft) and were driven to depths ranging from 13 to 20 m (42 to 68 ft). A foundation layout and pile delineation plan is illustrated in Figure 2.

Probe and production piles were installed with an ICE 520 diesel double-acting hammer rated at 4,200 m-kg (30,000 ft-lbs) maximum rated energy. It was equipped with a bouncing chamber pressure gauge and properly maintained hammer cushion. The hammer was equipped with 3 fuel settings to control the chamber pressure and the ram stroke. For this project site the hammer was operated at the highest fuel setting at all times and the ram did not stroke high at the beginning of driving because the soil resistance was low. Special precaution was also taken to maintain proper pile cushion.

During the logging and monitoring of the production pile driving operation 492 PPC piles were rated for 363 kN (40 tons) and 55 were rated for 245 kN (27 tons) allowable capacity based on either the end of initial drive (EOID) or beginning of redrive (BOR) results. Piles that did not meet the driving criteria randomly selected piles were retapped to verify pile capacity after set-up.

Based upon ASC's continuous and satisfactory monitoring of the pile installation program (e.g., logging the blowcount, periodic checking of hammer energy, and keeping track of pile embedment) the PPC pile foundation system, as installed, was approved and accepted for the building. The Waterside Building 1 project was completed in April 1997. The building was released for occupancy after completion of the project and to date all the structure has performed well.



LEGEND	
144 COLUMN OR PILE CAP NUMBER	
▪ PP12 PROBE PILE NUMBER	
LENGTH (ft)	# OF PILES
43	25
45	145
48	15
50	58
53	45
55	49
63	70
65	88
70	10
75	54
TOTAL	559

Figure 2. Foundation Layout and Pile Delineation Plan

OBSERVATION, REMARKS, CONCLUSIONS

The authors believe that the use of properly installed and effectively monitored and tested precast prestressed concrete piles was economical as compared to other deep foundation systems and that PDA proved to be a key element of the overall approval and acceptance process.

1) It is important to have an accurate and reliable method of calculating axial pile capacity. Although several methods exist for designing axially loaded piles, every design method should be verified for applicability to a specific site prior to use. The SPT94 software was selected for this project due to its applicability to foundations in Florida soils.

2) Cost of the selected and installed pile foundation utilizing PDA was generally less than that of other deep foundations such as auger-cast or vibrated concrete piles and concrete drilled shafts. It resulted in a cost saving of 15 to 20 percent. The speed of foundation installation was helpful in completion of the project ahead of schedule

3) Optimization of pile penetration depths and capacities (ref 1) was based on PDA assisted probe pile driving program.

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and Associates, the project architect; Jenkins & Charland, Inc., the structural engineer; and Southern Gulf West Construction, Inc., as well as Island Piling, Inc., the contractors all from southwest Florida.

The case history information from this project provided a useful database for reference on future projects of this type in this area of southwest Florida. The authors also wish to thank Manish Dharnidharka for preparation of diagrams presented in this paper.

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