Technical Paper

Title: Designed, Load-Tested, Installed, and Integrity-Tested ACIP Piles at Lovers Key Site in Southwest Florida

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DESIGNED, LOAD TESTED, INSTALLED, AND INTEGRITY TESTED ACIP PILES AT LOVERS' KEY SITE IN SOUTHWEST FLORIDA

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ABSTRACT

A case history of design, prediction, instrumented static load tests on probe piles, installation monitoring, and integrity testing of production piles is presented. Based upon project-specific subsoil conditions, as obtained from several 60 to 80 ft (18.3 to 24.4 m) deep test borings, deep foundation system alternatives included driven concrete and steel pipe piles as well as augered cast-in-place (ACIP) piles. High structural loads, site-specific constraints, and the production time frame mandated by the project owner led to the selection of an ACIP pile foundation system that was designed for a pile capacity of 75 tons (667 kN) in compression and 35 tons (309 kN) in tension.

Site-specific concerns were raised about the highly porous nature of fragmented and decomposed sandy limestone as well as the high grout intake during construction that could result in increased foundation cost as well as interconnecting of the piles in the rock layer. Consequentially, a multi-phase ACIP pile evaluation programme consisting of instrumented compression pile load tests, in conjunction with single-hole ultrasonic pile testing, pile echo testing (sonic testing), as well as full-time production pile monitoring by an experienced geotechnician was specified. As a result of this testing and evaluation program, while grout usage was determined to be within an acceptable range, the instrumented compression load tests yielded data that allowed use of 55 ft (16.8 m) long ACIP piles in lieu of the original plans to use 70 ft (21.3 m) long precast concrete piles.

This information was effectively utilized as part of the overall quality control program to install a total of 268, 14 in. (356 mm) diameter ACIP piles within the building footprint to depths of 55 ft (16.8 m) below the pile cut-off elevation as part of the foundation support system. Information recorded during installation included rate of insertion/extraction of the auger, grout pump strokes and pressure, total grout volume, and grout factors, as well as quality and strength of grout. Additionally, many pre-selected installed piles were tested for integrity with a Pile Integrity Sonic Analyzer (PISA) using both sonic and ultrasonic methods.

This engineered, monitored, and tested foundation solution provided an effective and quality intensive basis for completion and approval of the foundation work for the building that resulted in cost savings over other foundation alternatives for the owner.

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INTRODUCTION

The Lover's Key Beach Club & Resort is a 14-story waterfront structure on Black Island (also known as Lover's Key) located south of Fort Myers Beach in Lee County, Florida, USA. The structure is bound by Estero Bay to the east, Big Carlos Pass to the north, the Lover's Key State Recreation Area to the south, and a lake to the west. Two mid-rise condominium structures exist to the northwest of the subject structure. The project consists of an ACIP pile foundation system, reinforced concrete pile caps and grade beams, reinforced concrete columns and shear walls, post-tensioned elevated floor slabs, and concrete slabs-on-grade. The project layout plan, identifying the building footprint and test boring locations are illustrated in Figure 1.

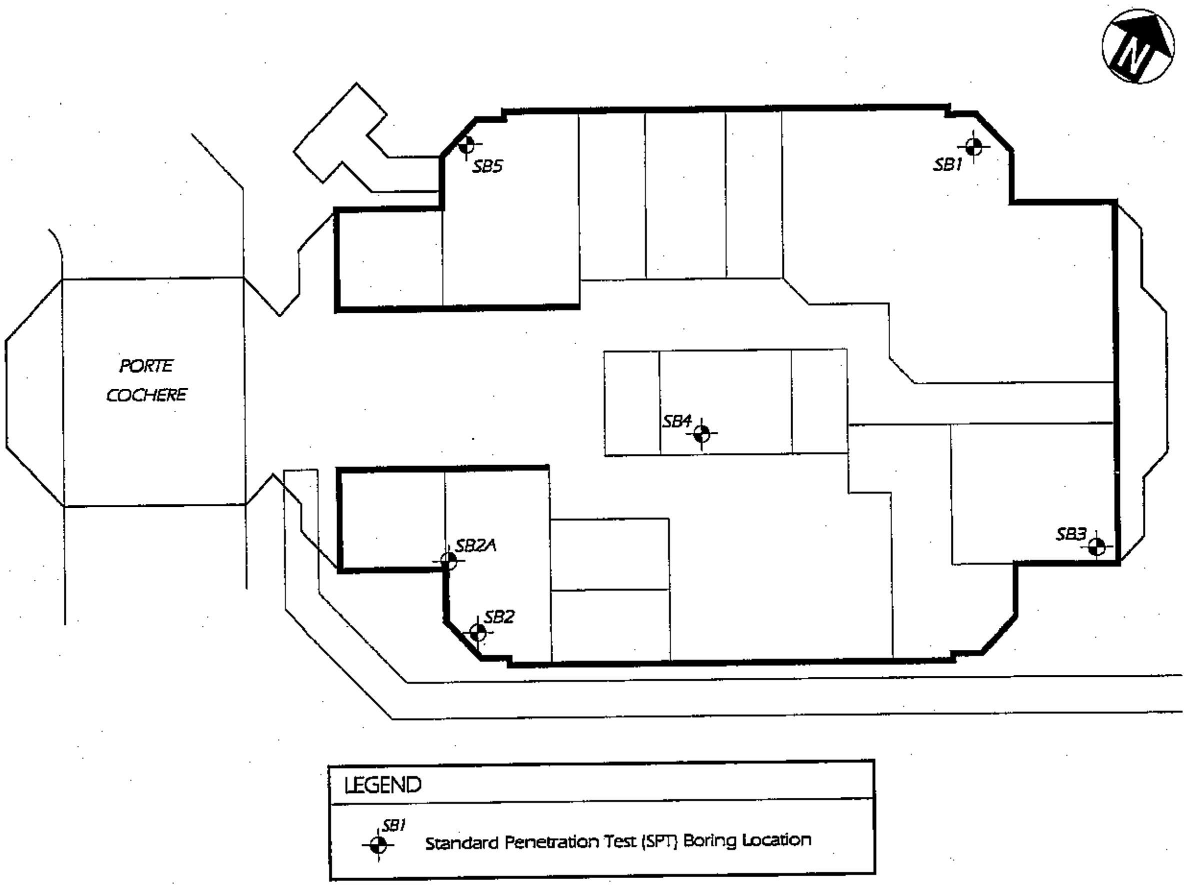


Figure 1. Project layout and test boring location plan

SUBSURFACE SOIL AND GROUND-WATER CONDITIONS

The project site was sandy with generally level topography. The geometry of the site, the proximity of existing buildings to the subject structure, and the fact that site is bound by water to the north, east and west created a condition where space for staging of construction was very limited. The detailed geotechnical exploration program consisted of advancing a total of six (6) Standard Penetration Test (SPT) borings. Two (2) borings were drilled to depths of 80 ft (24.4 m), three (3) borings were drilled to depths of 60 ft (18.3 m), and one (1) boring was drilled to a depth of 35 ft (10.7 m) below the existing ground surface to explore the subsurface soil and ground-water table conditions. Generalized subsurface soil and ground-water conditions compiled from these six (6) test borings are illustrated graphically in Figure 2.

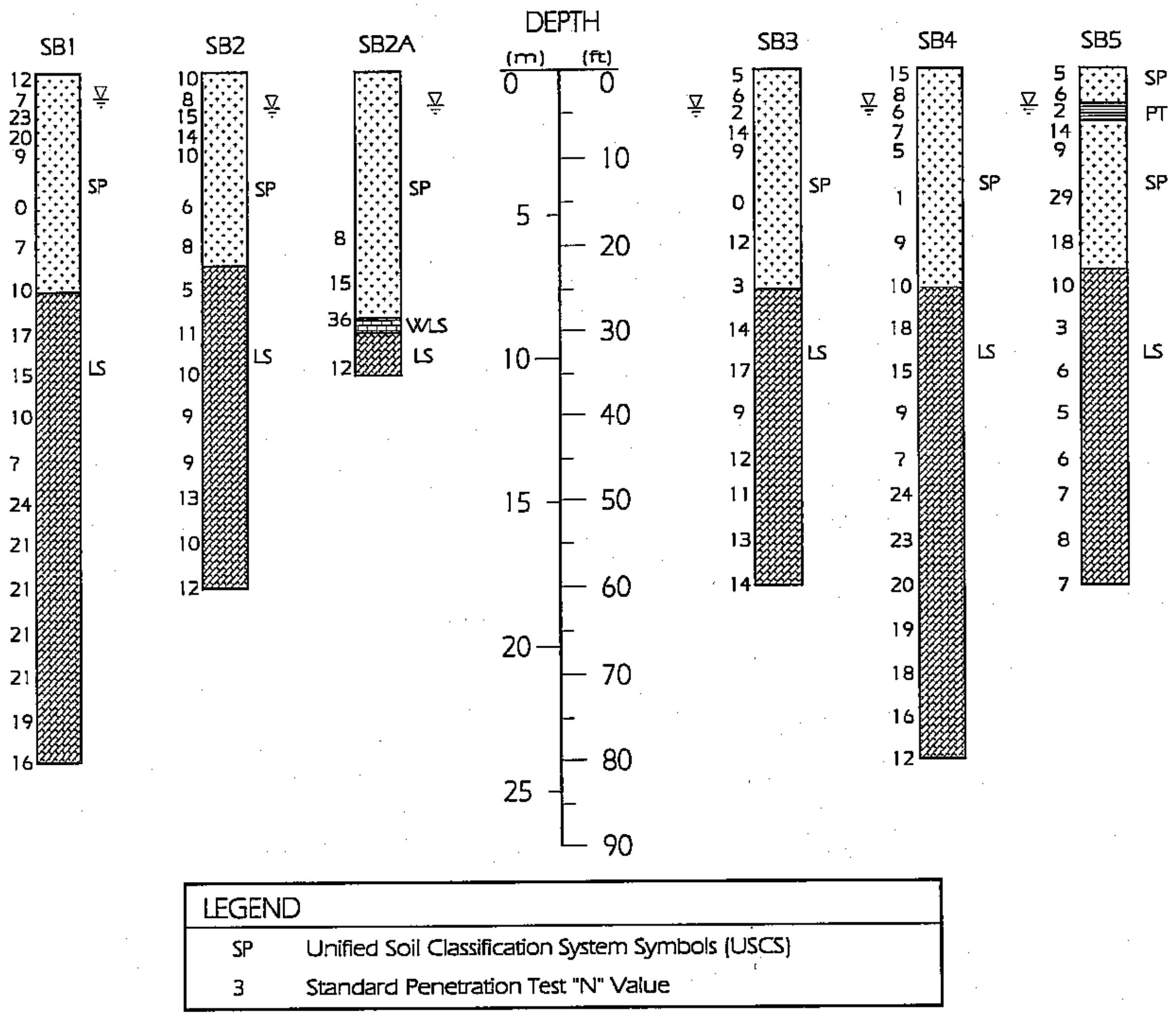


Figure 2. Summary subsurface profile (stratigraphy)

In general, project site stratigraphy consisted of very loose to medium dense poorly-graded sands (SP) from the egs to depths of approximately 22 to 25 ft (6.7 to 7.6 m). These surficial sands are underlain by generally loose to medium dense decomposed sandy porous limestone (LS) to the boring termination depths 60 to 80 ft (18.3 to 24.4 m) below the egs. An approximately 1.5 ft (0.5 m) thick layer of peat with sand (PT/SP) was encountered in boring SB5 from 4.5 to 6.0 ft (1.4 to 1.8 m) below the egs.

PROJECT FILL REQUIREMENT AND STRUCTURAL DATA

The plan area of the 14-story mid-rise structure is approximately 10,000 sq ft (929 sq m). Maximum column loads were reported by the project structural engineer to be on the order of 750 tons (6665 kN). Approximately 2 to 3 ft (0.6 to 0.9 m) of fill was required to achieve the desired finish grade. Foundation support recommendations for the proposed structure included both driven concrete and ACIP pile. However, the ACIP pile foundation was ultimately selected by the project architect and owner based on a number of factors summarized below.

- the extremely close proximity of existing mid-rise condominium buildings adjacent to the project site. Consideration was given to both the noise associated with driven pile operations in a vacation resort area and the possibility of damage to nearby structures, possibly created by vibrations from pile driving operations. As previously stated, the site was extremely confined and did not provide adequate space for staging of construction. Storage room for driven concrete piles, therefore, was extremely limited.

- the stringent time frame assigned for pile installation as presented in the project construction schedule.

- relative cost of the ACIP pile system versus a driven concrete pile system.

TEST PILE INSTALLATION AND LOAD TEST PROGRAM

A 3-phase quality control program for installation and approval of the ACIP pile foundation system for the project was specified by the geotechnical consultant. The quality control program consisted of (1) installation and load testing of two instrumented test piles, (2) full-time production pile monitoring by an experienced geotechnician, and (3) pile integrity testing of approximately 10 percent of installed production piles using the Pile Integrity Sonic Analyzer (PISA) unit to verify effectiveness of installation.

Two (2) instrumented compression load test piles (along with associated reaction piles) were installed at locations pre-selected by the geotechnical consultant. A 55 ft (16.8 m) long test pile was installed in a non-production pile location (i.e., the pile was abandoned after completion of the load test program), and a 65 ft (19.8 m) long test pile was installed in a production pile location. Both piles were to be tested in compression and were instrumented with vibrating wire strain gauges. It should be noted that both piles were originally planned to be 65 ft (19.8 m) long, but one test pile (at the non-production pile location) was shortened so that it could be tested to failure to determine the ultimate compressive pile capacity. An experienced geotechnician performed quality control testing on the pile grout and cast compressive strength specimens for use in determination of strength prior to load testing the piles. No unusual conditions were observed during the installation of the test piles. The compression test piles were installed with grout factors of 1.18 and 1.37, or 118 to 137 percent above the theoretical volume of the piles. The observed grout factors were lower than anticipated, indicating that the fractured and decomposed sandy limestone encountered in the test borings was not as porous as expected. The grout factors were favorable for ACIP pile installation, since grout costs would be less that expected and because interconnection of piles would likely not be a problem during production pile installation.

Compression static load tests were performed to twice the design compression pile capacities as required by the building code. Specifically, the compression test piles were loaded to 150 tons (1333 kN), or twice the design capacity of 75 tons (667 kN). Following completion of the record compression load tests, the 55 ft (16.8 m) test pile was loaded to 210 tons (1866 kN) in an attempt to cause failure and determine the ultimate compressive pile capacity. The pile, however, did not fail up to an applied load of 210 ton (1866 kN) and the test was terminated since the maximum capacity of the load test reaction frame was being approached. Although the pile failure load was not reached, valuable information was obtained related to reserve capacity in the pile that is often required to account for mis-located and consequentially over-stressed production piles. Pile top displacement versus applied test load curves for the compression load tests are presented in Figure 3. The compression load test data indicated that the 14 in. (356 mm) diameter and 55 ft (16.8 m) long piles would satisfactorily carry the design loads with applied safety factors and within pile top displacement values allowed by the Standard Building Code and in accordance with project-specific requirements.

GEOPHYSICAL INSTRUMENTATION (VIBRATING WIRE STRAIN GAUGES)

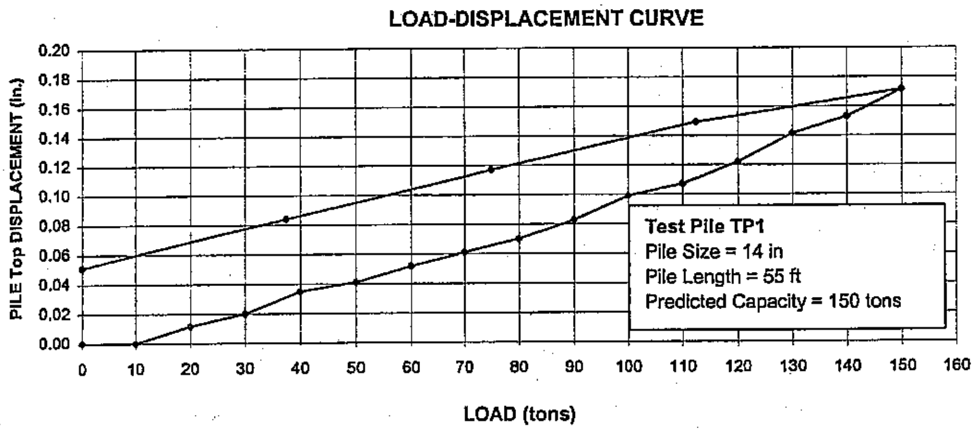
The compression test piles were instrumented with vibrating wire strain gauges to determine the load distribution profile with depth. Vibrating wire strain gauges (VWSG) are attached to the pile reinforcing steel and cast into the pile during construction. They consist of a calibrated wire tensioned to a known distance between two end blocks. The theory is that the VWSG experiences the same deformation as the pile grout as the pile is loaded (i.e., the same elastic deformation). The gages are connected with electrical wires to a power source and digital readout box. At each applied load increment during the load test a signal is sent to a plucking coil, which plucks the wire and creates a vibration. The frequency of the vibration is recorded and referenced to a change in length, or strain. The strain in the strain gauge is assumed to be equal to the strain in the pile section. Knowing the strain at each load and the grout elastic modulus allows a calculation of stress along the pile profile. The stress can be determined at whatever depths the gauges are installed. The applied load minus the stress transferred at the applied load is load energy dissipated in the form of skin friction.

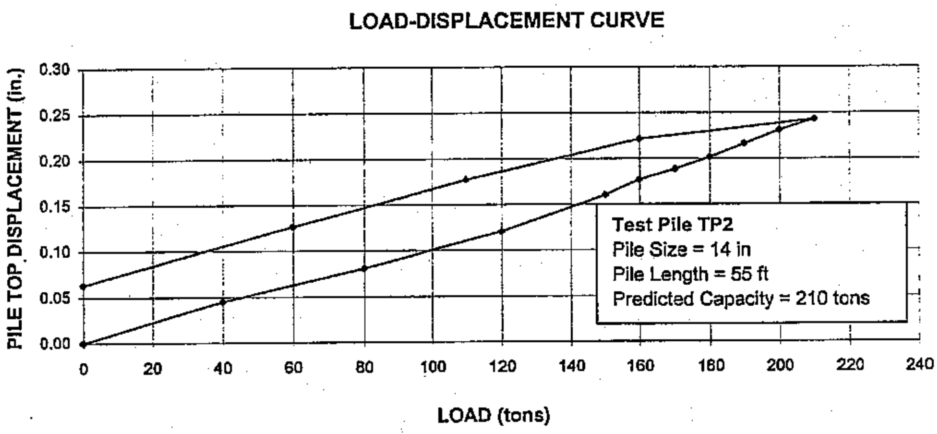
There are several methods utilized to determine the elastic modulus of the grout. The preferred method is to install a strain gauge within 2 ft (0.6 m) of the ground surface elevation. Since the friction developed in the upper portion of the pile immediately below the ground surface is negligible, the stress transferred (applied load divided by pile cross-sectional area) and the corresponding measured strain value can be used to calculate the elastic modulus. Illustrated in Figure 4 are the graphical representations of load distribution along the pile profile.

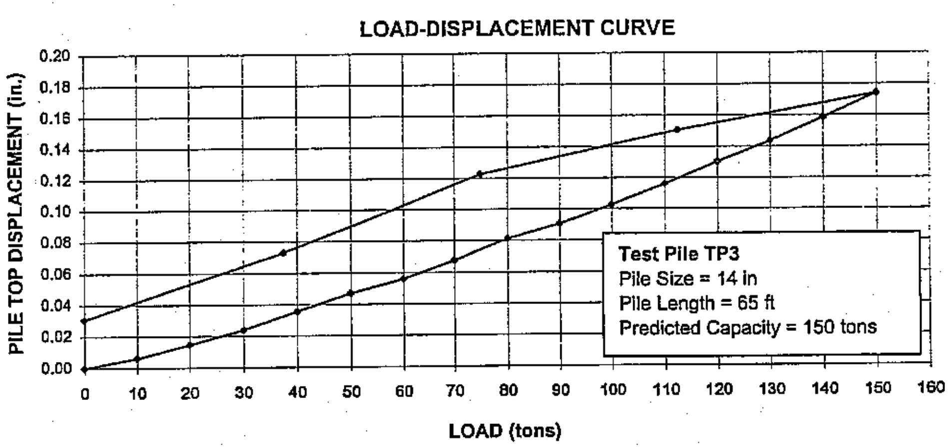
The load distribution profile and load-displacement data determined from the instrumented compression load test indicated that the piles could have been reduced in length to 50 ft (15.2 m). The 55 ft (16.8 m) production pile lengths were specified to account for lost embedment depth due to the thickness of the pile caps (i.e., approximately 5 ft (1.5 m) of the piles would be cut off after pile caps were excavated).

PRODUCTION PILE INSTALLATION

Following the geotechnical consultant's review of the pile layout plan, production pile installation commenced and a total of 268, 14 in (356 mm) diameter and 55 ft (16.8 m) long piles were installed during 6 days of production, under the full-time installation monitoring and direct







LOADING TEST TYPE	PILE SIZE		CAPACITY[2]		GROUT FACTOR
	WIDTH (in)[1]	LENGTH (ft)[1]	PREDICTED (tons)[1][2]	DAVISSON (tons)[1]	
COMPRESSION (TP1)	14	55	150	----[3]	1.18
COMPRESSION (TP2)	14	55	210	----[3]	1.18
COMPRESSION (TP3)	14	65	150	----[3]	1.37

NOTES: (1) 1 in = 25.4 mm.; 1 ft= 0.30 m; 1 ton = 8.90 kN
(2) Maximum load applied during static load test
(3) not attained

Figure 3. Load displacement curves for test piles TP-1, 2 and 3

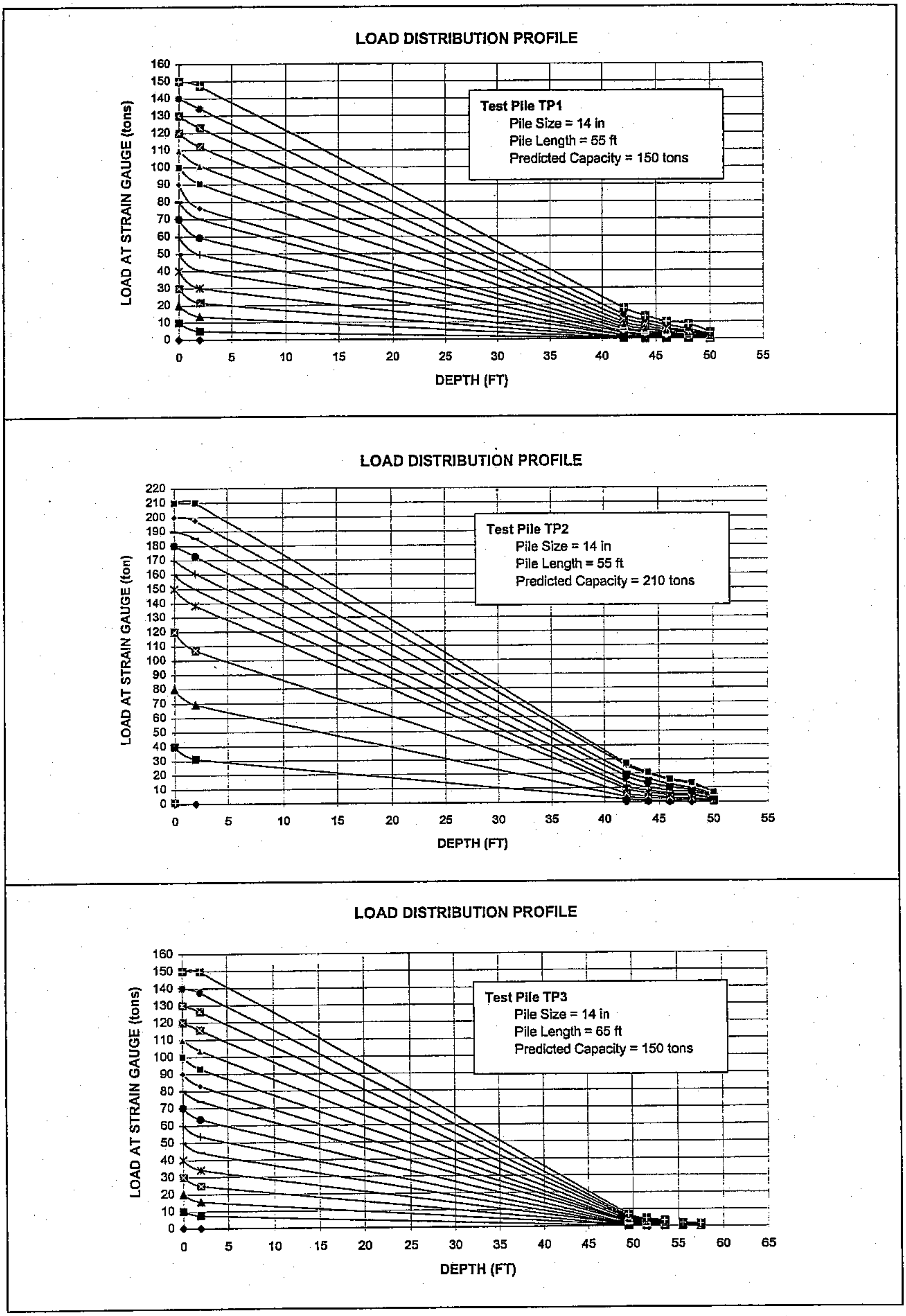


Figure 4. Load distribution plots from instrumented compression load tests

supervision of the geotechnical consultant. Grout factors ranged from 1.15 to 1.35, with an overall grout factor of 1.27. These relatively low grout factors indicated that pile interconnection was not likely occurring. Pile installation logs were prepared to document the times required to insert and extract the auger, the grout quantity placed into the pile, and any unusual observations noted during pile installation. These logs could then be reviewed along with the graphical ultrasonic test results obtained from the PISA unit for the same pile, as discussed below. Pile layout and other details are illustrated in Figure 5.

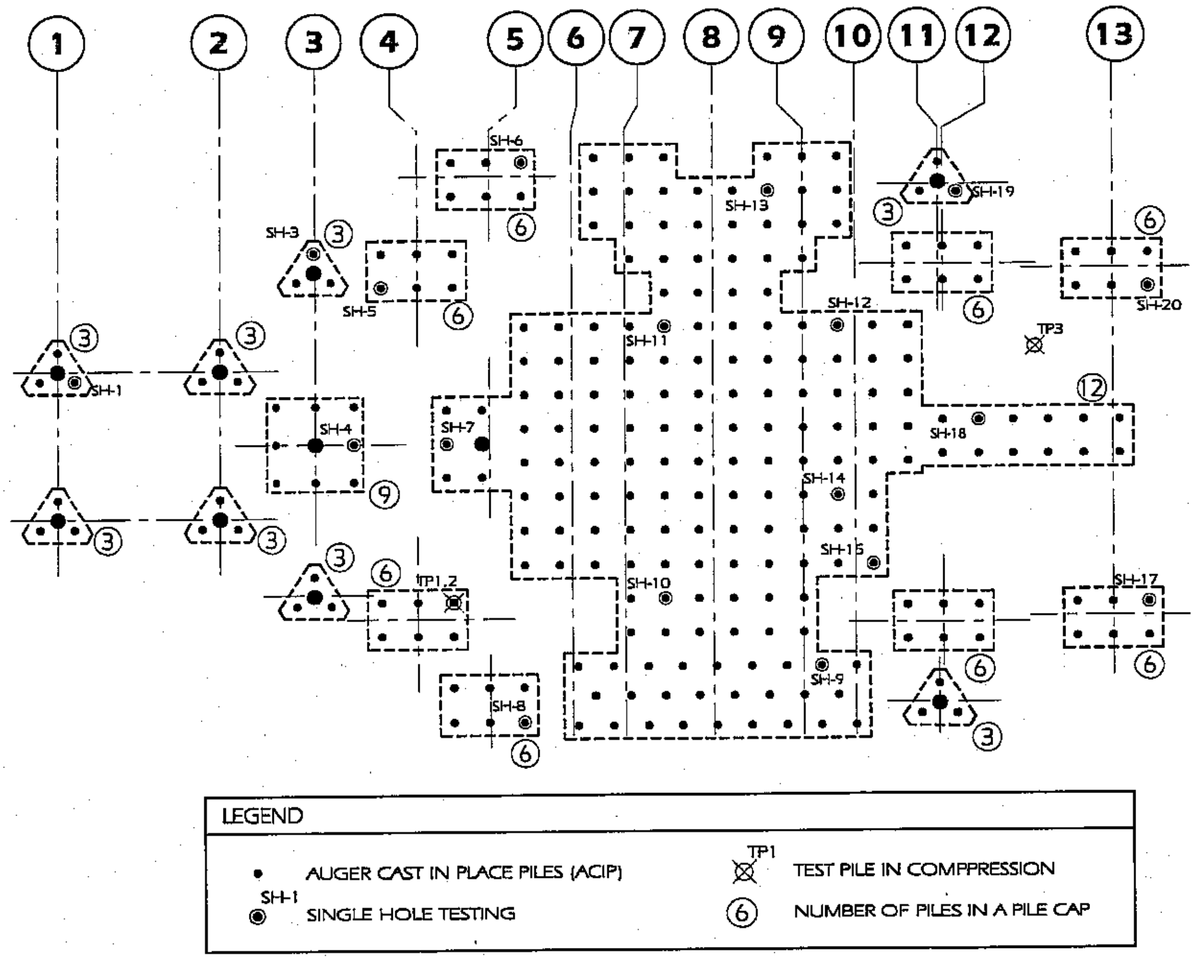


Figure 5. Pile layout plan, static load tests, and sonic test locations

PILE ULTRASONIC INTEGRITY TESTING USING PISA UNIT

A total of 18 production piles were pre-selected by the geotechnical consultant for single-hole ultrasonic testing using the Pile Integrity Sonic Analyzer (PISA). In order to test the pile after installation, a single 1.5 inch I.D. PVC tube was attached to the central reinforcing bar in the pile and cast into the pile. The access tube was filled with water immediately following installation to maintain near-constant temperatures and minimize effects of de-bonding between the PVC tube and the surrounding grout material. De-bonding can create voids that effect the quality of the data obtained with the PISA.

The PISA can be used for cross-hole ultrasonic logging (with 2 or more access tubes) or single-hole ultrasonic logging with a single access tube. Cross-hole ultrasonic testing is typically reserved for larger diameter pile sections or drilled shafts where installation of multiple tubes is more easily facilitated and the distance between the access tubes is large enough to allow effective transmission and receipt of the ultrasonic signal. For 14 in. (356 mm) diameter piles, single-hole ultrasonic testing was selected.

In single-hole sonic testing, a transmitter and receiver are lowered into the single access tube separated by a defined distance. The distance can be adjusted (often by trial and error) to change the size of the sphere through which ultrasonic signals are transmitted and received. The sphere size is adjusted so that the entire cross-section of the pile is evaluated, but limited so that the ultrasonic signals are not passing through the surrounding soil materials. An excellent benefit of this testing procedure is that increases in pile cross-section are not normally detected since the sphere does not project past the nominal diameter of the pile. Reductions in cross-sectional area, however, are easily detected. Reductions in cross-section are reasons for concern whereas moderate increases in pile cross-section generally are not.

The PISA utilizes a windows based program run on a laptop computer. Its portability and ease of use allows the testing of many piles in a short time. Furthermore, the computer reduces and processes the test data in real-time, allowing on-site evaluation of pile integrity during testing. The data can be downloaded and the results printed directly into a summary report.

There are several methods used to present the data obtained from the PISA unit. The most common method is a plot of signal First Arrival Time (FAT) and amplitude. Typical graphical representations of the test data for piles SH 2, SH 8 and TP 1 are illustrated in Figure 6. FAT is represented by the left edge of the plot while amplitude (i.e., the inverse of the signal energy) is represented by the thickness of the plot. A thinner plot, therefore, represents higher energy. Voids within the pile section, pile necks, soil inclusions/contamination, or significant changes in grout quality will normally change both signal amplitude and FAT, and are normally represented by a shift to the left in the plot. The nature of ACIP piles will lead to minor shifts along the pile profile, so minor shifts are generally interpreted as insignificant. For the Lover's Key project it should be noted that the depth at which the amplitude is most narrow (i.e., highest signal energy) on the plots corresponds with the approximate depths of limestone material encountered during drilling of both the test borings and the production piles. Immediately above the elevation of the top of rock (i.e., in the generally very loose to medium dense surficial sands) the signal amplitude widens, indicating lower signal energy. This condition indicates a roughly 20 to 40 percent reduction in signal velocity above the top of the rock, which was possibly caused by setting the transmitter and receiver at a separation distance that created a slightly large test sphere. The test sphere most likely included a portion of the pile considered to be a transition zone around the extreme circumference of ACIP piles that is not undisturbed soil or pure pile grout. This transition zone below the top of rock included limestone material which is much more dense than the surficial sandy soils. The denser materials, therefore, exhibited smaller magnitude FAT and higher energy. It is evident that anomalies of real consequence, such as soil inclusions, voids, or necks, would reduce signal velocities much more than the indicated 20 to 40 percent. PISA data together with the installation monitoring data indicated that all tested piles were satisfactorily installed and acceptance of the same installed foundation system was recommended.

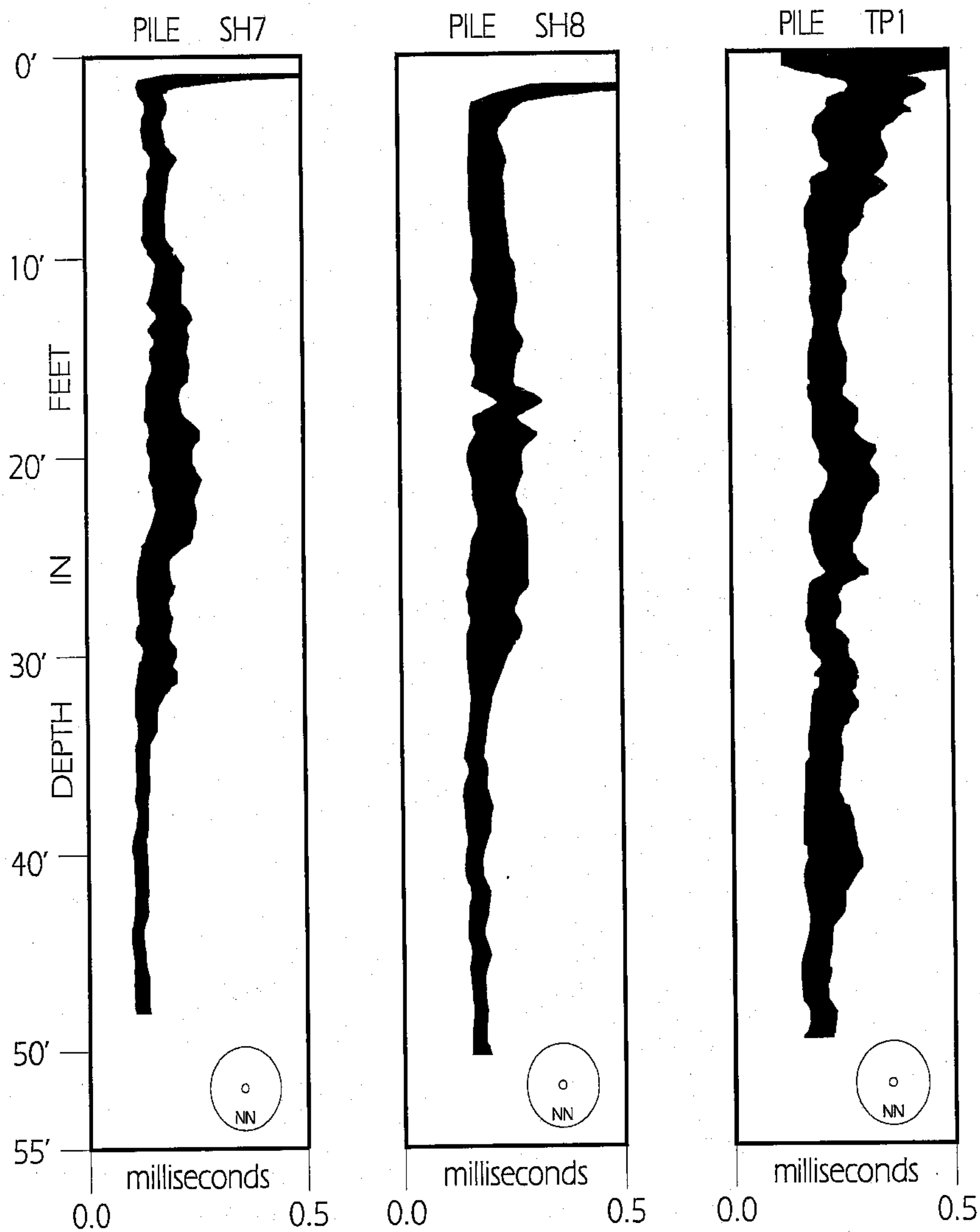


Figure 6. Typical signal attenuated first arrival time (FAT) traces

CONCLUSIONS

The comprehensive quality control program consisting of test pile installation monitoring and instrumented static load testing program, full-time production pile installation monitoring, and pile integrity testing led to a satisfactory foundation support system installed with a high level of confidence. The foundation system performed well and was installed ahead of schedule with a significant cost savings to the owner.

ACIP piles can neither be inspected not verified by visual means, unlike driven piles and other conventional deep foundations. Their installed quality is totally operator dependent.

The dual purpose Pile Integrity Sonic Analyzer (PISA) is a very useful instrument that allows quick and accurate testing of piles with dependable results (Amir et al 1998). Traditional pile integrity testing equipment is generally slower and is considered valid for testing piles shorter than 30 pile diameters long. The PISA unit successfully tested piles 47 pile diameters long with accurate and conclusive results. Use of this 3-phase comprehensive quality control approach on this project and others is essential to verify that the ACIP pile foundation system will perform as intended and designed. Furthermore, this approach has increased awareness in the design profession and construction industry for the usefulness of ACIP pile foundations systems.

This case history confirmed that project team members were knowledgeable professionals who could rationally assess the risks involved and were not opposed to innovation as a means of reducing costs and achieving economy (Saxena et al 1997). Furthermore, this experience shows the reliability of sonic integrity testing can be improved by supplementing it with carefully implemented pile installation monitoring program including automated monitoring systems and ultrasonic testing on selected piles where access tubes were pre-installed. Lastly, advances in sensing instruments and computer technology will allow the ACIP piles to be installed with confidence.

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