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DESIGNED AND LOAD TESTED ACIP PILES FOR A MID-RISE CONDOMINIUM IN SOUTHWEST FLORIDA - A CASE HISTORY

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ABSTRACT A case history of design, prediction, static load tests on probe piles, and installation monitoring of production piles for a 12-story waterfront condominium building located in Fort Myers Beach, Lee County, Florida, USA is presented. The subsurface soils were explored by performing test borings to depths of 30.5 m (100 ft) within the building footprint. Abandonment of a previously installed driven pile foundation system became necessary following preliminary testing that determined their length to be only 3.3 m (11 ft). High structural loads, site-specific constraints, and the owner specified production time frame justified an auger cast-in-place (ACIP) pile support system as the most effective foundation approach. The building foundations were designed for a pile capacity of 711 kN (80 tons) in compression and 311 kN (35 tons) in tension. During the design construction phase, a total of two static pile load tests (one each in compression and tension) were performed on 356 mm (14 in.) diameter and 27.4 m (90 ft) long un-instrumented piles. This information was effectively utilized as part of the overall quality control program to install a total of 349, 356 mm (14 in.) diameter concrete piles within the building footprint to depths of 27.4 m (90 ft) below the pile cut-off elevation, as part of the foundation support system. During full-time monitoring of the production pile installation operation, 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, were recorded. Prior to accepting the installed foundation system, ten percent of the piles were also tested for integrity utilizing a Pile Echo Tester (PET).

This engineered, monitored, and integrity tested pile foundation solution provided a cost-effective and satisfactory basis for completion and approval of the foundation work for the building and resulted in cost savings over other foundation alternatives for the owner.

ABSTRAIT Une histoire du cas de conception, prédiction, épreuves de la charge statiques sur tas de l'enquête, et écoute de l'installation de tas de la production pour un 12-story bâtiment d'appartement a localisé sur Fort Myers Plage, Comté de l'Abri, Florida, USA est présenté. Les sols subsurfaces ont été explorés par représentation teste des foruses à profondeurs de 30,5 m (100 ft) dans l'empreinte de pas du bâtiment. Abandonnement d'un systéme de la fondation du tas commandé, précédemment installé, est devenu nécessaire suivant, des essais préliminaire, qui a déterminé que leur longueur étaient seulement 3,3 m (11 ft). Hautes charges structurelles, contraintes emplacement-spécifiques, et le propriétaire a spécifié le temps de la production encadre justifié un jet-in-endroit de la tarière (ACIP) système du support du tas comme la fondation l'approche la plus éfficace. Les fondations du bâtiment ont été conçues pour une capacité du tas de 711 kN (80 tonnes) dans compression et 311 kN (35 tonnes) en tension. Pendant la phase de la construction de la conception un total de deux épreuves de la charge du tas statiques (un chaque en compression et tension) a été exécuté sur 356 mm (14 in.) diamètre et 27,4 m (90 ft) long a un-instrumenté tas. Cette information a été utilisée efficacement comme partie de la qualité totale commande le programme installer un total de 349. 356 mm (14 in.) diamètre concrétise tas dans l'empreinte de pas du bâtiment à profondeurs de 27,4 m (90 ft) en dessous le tas élévation coupe-éteinte, comme partie de la fondation supporte le système. Entassez-vous pendant écoute à plein temps de la production opération de l'installation, taux d'insertion/ extraction de la tarière, coups de la pompe du coulis et pression, volume du coulis total, et agents du coulis, aussi bien que qualité et force de coulis, a été enregistré. Antérieurement à accepter que l'installe le système de la fondation, dix pour cent des tas ont été testés aussi utilise pour intégrité un Pile Echo Tester (PET).

Celui-ci a construit, a dirigé, et a intégrité testé pour la solution de la fondation a fourni une base coût-efficace et satisfaisante pour achèvement et approbation de la fondation travaille pour le bâtiment et a eu comme résultat d'économies du coût sur autre alternatives de la fondation pour le propriétaire.

1. INTRODUCTION

The Gullwing Beach Resort condominium is a 12-story beachfront structure bound by the Gulf of Mexico to the west and Estero Boulevard to the east in Fort Myers Beach, Lee County, Florida, USA. Mid-rise condominium structures exist both to the north and south of the subject site. 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, test boring locations, as well as the site geometry, are illustrated in Figure 1.

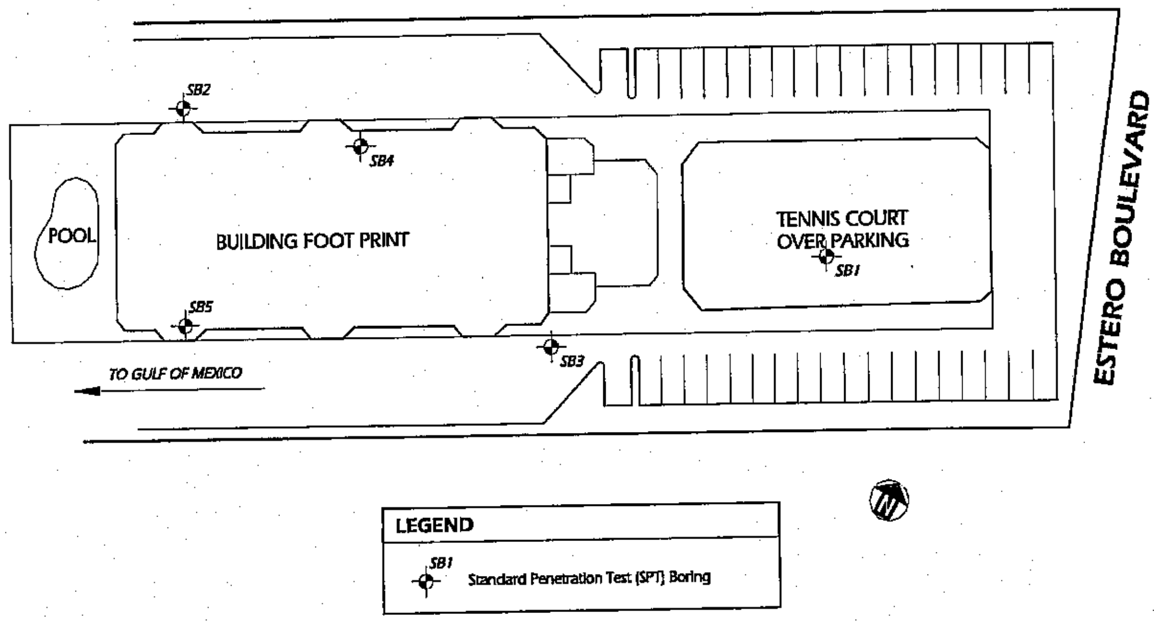


Figure 1. Project layout, site geometry, and test boring location plan

As part of a previous and similar project contemplated for the site, a prestressed precast concrete driven pile foundation system was installed. Individual piles, pile caps, as well as ground floor columns were left over from the previous project's cancellation. Neither the pile driving records nor the installed pile length information was available, so the project owner authorized ASC to investigate and determine the length of the existing piles at the site.

Following removal of the columns and pile caps, ASC evaluated the existing piles using sonic testing equipment known as a Pile Echo Tester (PET). The PET uses sonic wave theory to estimate pile length and/or evaluate the integrity of installed piles. Knowing the approximate wave speed through a material allows an estimate of pile length or, conversely, knowing pile length allows an accurate estimation of wave speed. Assuming a reasonable and typical value for wave speed based on the typical compressive strength of concrete used in casting of precast concrete piles, Existing piles were estimated to be approximately 11 ft (3.3 m) long. Extraction of several piles confirmed the previously estimated pile length. The PET unit is a Windows based program that runs on a laptop computer. The small size of the equipment and ease of use allowed testing of a large number of existing piles in a single day, during which all piles were determined to be 11 ft (3.3 m) long.

These short piles could not be used since they did not meet the minimum embedment depth criteria of the regulatory agency of the State of Florida for piles installed in velocity (or "V") zones in coastal areas. These piles, therefore, were removed as part of the demolition process. A detailed subsurface soils exploration and geotechnical exploration program was undertaken to provide foundation pile recommendations for the new tower and the parkade structure.

2. SUBSURFACE CONDITIONS

Pre-construction site features included a narrow and deep beachfront tract of land with generally level topography. The detailed geotechnical exploration program performed by ASC consisted of advancing a total of five (5) Standard Penetration Test (SPT) boring using conventional drilling and sampling techniques. Four (4) borings were drilled to a depth of 33.5 m (100 ft) and one (1) boring was drilled to a depth of 15.2 m (50 ft) below the ground surface elevation to explore the subsurface soil and ground-water table conditions.

In general, project site stratigraphy consisted of very loose to dense poorly-graded sands (SP), poorly-graded sands to silty sands (SP-SM) to depths of approximately 7.0 to 8.5 m (23 to 28 ft). These surficial sands are underlain by generally loose weathered and/or fractured limestone (WLS) to a depth of 11.6 m (38 ft) below the ground surface. Generally very loose to loose silts (ML) underlie the weathered limestone to approximately 17.7 m (58 ft) where firm to very stiff lean sandy clays (CL) exist and continue to the boring termination depth of 33.5 m (100 ft) below the ground surface. Generalized subsurface conditions compiled from these five (5) test borings are illustrated in Figure 2.

3. FOUNDATION DESIGN DATA

Preliminary design loads provided by the project structural

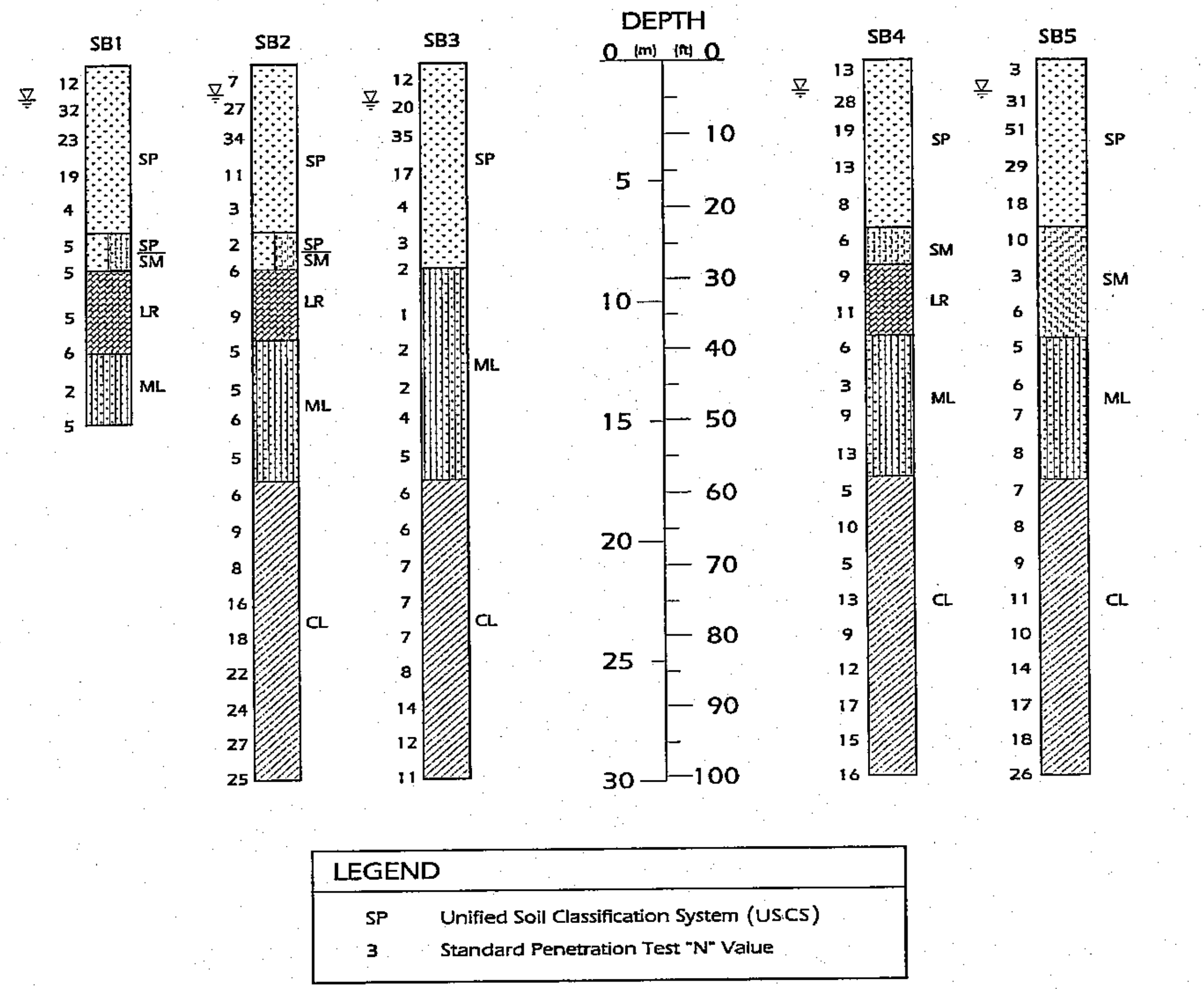


Figure 2. Summary subsurface profile (stratigraphy)

engineer were evaluated along with the subsurface soil conditions at the site. Maximum and minimum column loads were reported to be on the order of 1555 kN (175 tons) and 4177 kN (470 tons), respectively. Shear wall loads were reported to be on the order of 12087 kN (1,360 tons).

Both driven concrete pile and ACIP pile types were evaluated and recommended for foundation support for the proposed structure. The ACIP pile foundation was ultimately selected by the project architect and owner based on the following considerations summarized below.

□ the extremely closed proximity of existing mid-rise condominium buildings to both the north and south of the project site. Consideration was therefore given to both the noise associated with driven pile operations in a vacation resort area and the possibility of damage to nearby structures created by vibrations from pile driving operations.

□ accelerated construction schedule and the stringent time frame assigned for pile installation.

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

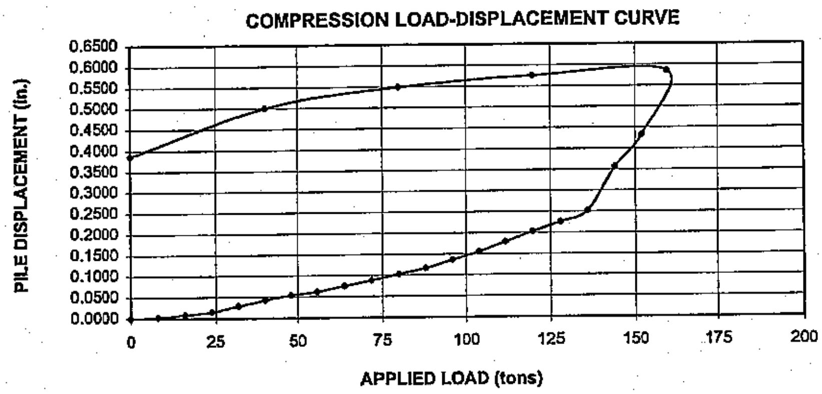
3. TEST PILE AND LOAD TEST DATA

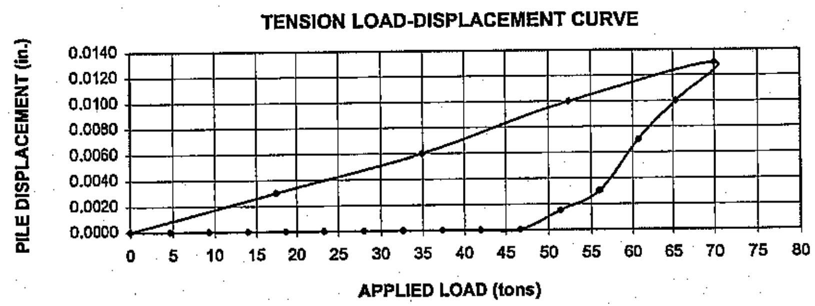
A 3-phase quality control program for installation and approval of the ACIP pile foundation system for the project was specified by the geotechnical consultant. The quality control program consisted of (1) installation and load testing of the probe/test piles, (2) full-time production pile monitoring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

One compression and one tension load test pile(s) as well as the reaction piles were installed at locations preselected by ASC. The test piles were installed at non-production locations (i.e., the piles were abandoned after completion of the load test program) under the direction of an engineering representative of the geotechnical consultant. 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 piles were allowed to cure and gain strength for 10 days and load tests were then performed general accordance with ASTM D1143, ASTM D3689, procedures.

Compression and static load test were performed to twice the design compression and tension pile capacities as required by the building code. Specifically, the compression test pile was loaded to 1422 kN (160 tons), or twice the design capacity of 711 kN (80 tons). The tension test pile was loaded to 622 kN (70 tons), or twice the design capacity of 311 kN (35 tons). Pile top displacement versus applied test load curves for the compression and tension load tests are illustrated in Figure 3.

Both the compression and tension load test data indicated that the 356 mm (14 in.) diameter and 27.4 m (90 ft) 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. The project owner elected not to install geophysical strain gauge instrumentation in the test piles so the pile length could not be shortened from the tested 27.4 m (90 ft) length.





LOADING TEST TYPE	PILE SIZE		CAPACITY(2)		GROUT FACTOR
	WIDTH (mm)(1)	LENGTH (m)(1)	PREDICTED (kN)(1)(2)	DAVISSON (kN)(1)	
COMPRESSION	356	27.4	1422 160	—(3)	1.77
TENSION	356	27.4	622 70	—(3)	1.35

NOTES: (1) 1 mm = 0.04 in.; 1 m = 3.28 ft; 1 kN = 0.11 tons

(2) Maximum load applied during static load test

(3) not attained

Figure 3. Load displacement curves and summary of test results.

4. PRODUCTION PILE INSTALLATION

Following the geotechnical consultant's review of the pile layout plan, production pile installation commenced and a total of 349, 356 mm (14 in.) diameter and 27.4 m (90 ft) long piles were installed under the full-time installation monitoring and direct supervision of engineering representatives of ASC. Grout factors (the actual volume of grout used to install the pile divided by the theoretical volume of the hole) ranged from 1.11 to 2.27. 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. A pile layout and other details are illustrated in Figure 4.

5. SONIC INTEGRITY TESTING

Following installation of the production piles at the site, a pile integrity testing program was implemented to further evaluate the installed piles relative to integrity of the pile shaft cross- section. Pile integrity testing was performed using Pile Echo Tester (PET). It uses wave propagation theory to evaluate the integrity of the pile section. An accelerometer/transducer is placed on the top of the pile and the pile top is struck with a hammer. The impact of the hammer causes a sonic wave to propagate down the pile shaft. Pile shafts with no anomalies and fairly uniform cross-sections will reflect the wave at the pile toe which will be received at the transducer at the top of the pile. The resulting graphical output from the PET is a plot of pile length versus impedance, and is commonly known as a reflectogram. Anomalies along the pile shaft such as necks, bulges, changes in material modulus of elasticity due to soil inclusions, etc. will send a wave reflection back from the point of contact while residual wave energy will continue down to the pile toe and be reflected back. As a result, pile reflectograms can be very difficult or impossible to interpret if many changes in cross-section occur, which is common in highly variable soils in southwest Florida in which relative density changes along the pile profile. Typical reflectograms obtained for piles tested on this project are included in Figure 5. Quality data was obtained from this testing program due primarily to the relative density of the surficial sands and cohesiveness of the clayey soils encountered at greater depths. The density and cohesiveness of the soils confined the grout pumped under pressure and allowed the installation of piles with fairly uniform cross-sections.

The results of the pile integrity tests indicated that the piles were installed properly without reduction in pile cross-section. The uniformity of cross-sections observed in the PET reflectograms was verified against uniformity in grout takes along the pile profile recorded on production pile installation logs.

6. CONCLUSIONS

The comprehensive quality control program consisting of test pile installation monitoring and 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 saving to the owner.

The PET unit is a very useful and relatively inexpensive instrument that allows quick and accurate testing of piles with dependable results. Traditional pile integrity testing equipment is generally slower and is considered valid for testing piles shorter than 30 pile diameters long. For this project, the PET unit successfully tested piles 77 pile diameters long with accurate and conclusive results. The recent advances in ultrasonic pile testing utilizing the dual purpose Pile Integrity Sonic Analyzer (PISA) have improved analysis and assisted in assuring a better product for the owner (Amir et al 1998). In addition, computerized pile installation records if supplemented with this 3-phase comprehensive quality control approach will assure that the ACIP pile foundation system will perform as intended and designed (Mirza et al 1994). This approach has increased awareness in the design profession and construction industry for the usefulness of ACIP pile foundations systems. Integrity of the ACIP piles is highly dependent on the skill of the contractor's field personnel. Accordingly, specialty subcontractors should be prequalified with respect to experience and quality (Saxena 1995).

7. ACKNOWLEDGMENT

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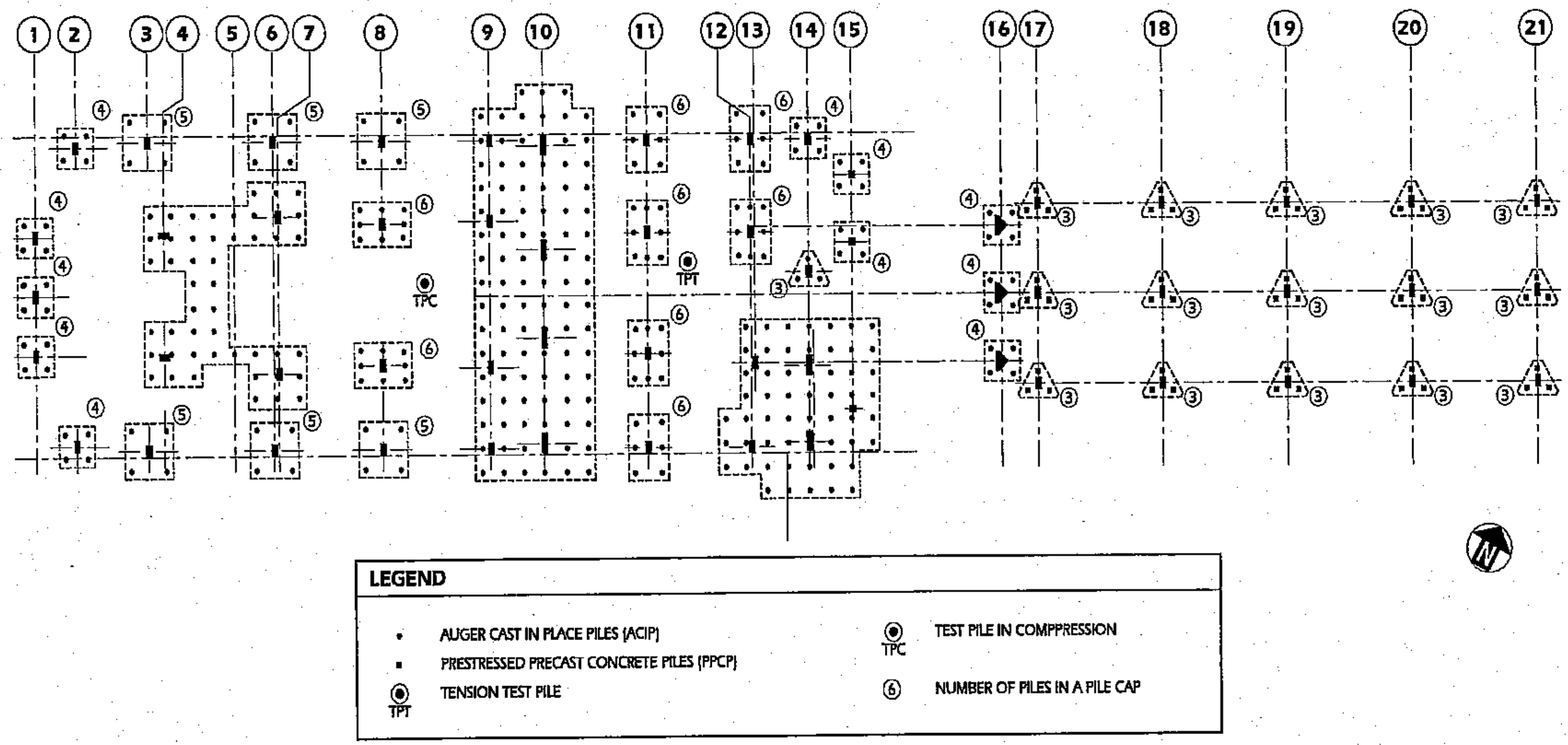
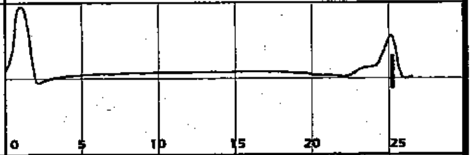
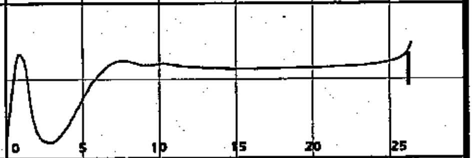
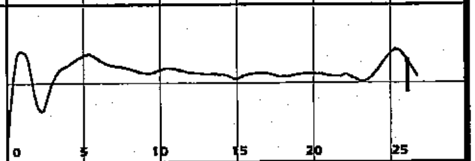
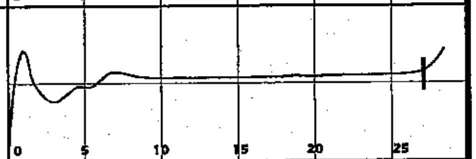
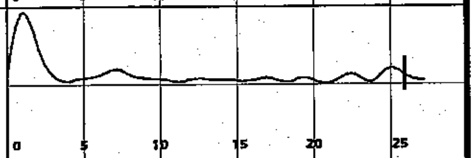
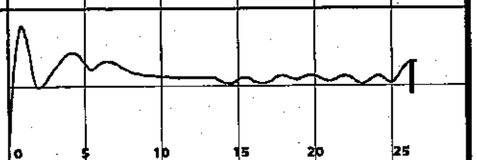
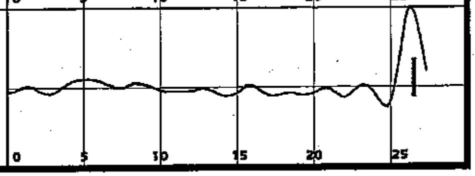


Figure 4. Pile layout plan and load test locations, tower and parkade area.

Length (m)	Details	Graph
25.2	Date: 01/27/99 c=4450 Avg: 3 Amp = 47	
26.2	Date: 01/27/99 c=4000 Avg: 0.4 Amp = 7	
26.1	Date: 01/27/99 c=4350 Avg: 7 Amp = 6	
27.1	Date: 01/27/99 c=3950 Avg: 8 Amp = 0.1	
25.9	Date: 01/27/99 c=4500 Avg: 3 Amp = 8.5	
26.3	Date: 01/27/99 c=3900 Avg: 9 Amp = 7.5	
25.5	Date: 01/27/99 c=4450 Avg: 4 Amp = 19	

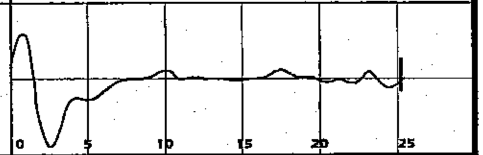
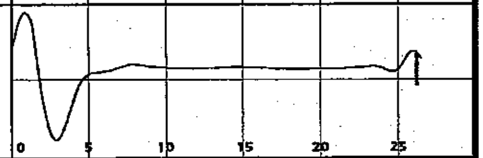
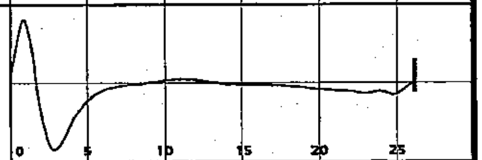
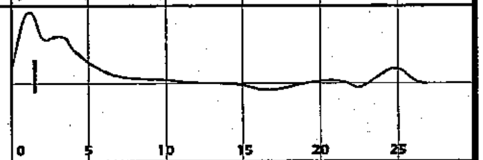
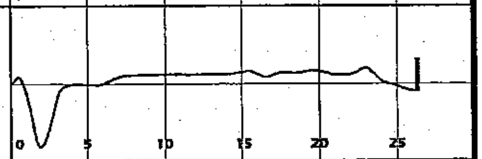
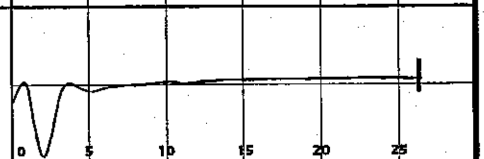
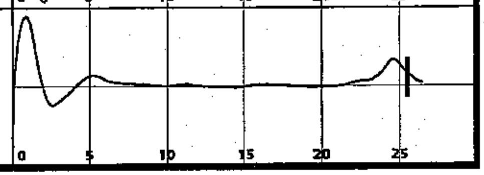
Length (m)	Details	Graph
25.4	Date: 02/17/99 3950 Avg: 10 Amp = 32	
25.3	Date: 02/17/99 c=4000 Avg: 70 Amp = 13	
25.1	Date: 02/17/99 c=4000 Avg: 12 Amp = 70	
2.5	Date: 02/17/99 c=4100 Avg: 8 Amp = 16	
25.9	Date: 02/17/99 c=4150 Avg: 3 Amp = 70	
24.8	Date: 02/17/99 c=4150 Avg: 6 Amp = 6	
25.0	Date: 02/17/99 c=4350 Avg: 13 Amp = 21	

Figure 5. Reflectograms of pile integrity testing by Pile Echo Tester (PET)