

Osterberg Cell Load Testing of High-Capacity Augered Cast-In-Place Piles

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INTRODUCTION

This paper discusses the recent implementation of Osterberg cell® (O-cell®) load testing technology, which has traditionally been utilized for load testing of drilled shafts, to the augered cast-in-place pile (ACIP) industry in the South Florida area. Since September of 2004, over a dozen O-cell tests in ACIP piles have been performed including load testing of ACIP piles of 150 feet (46m) in depth. Initially, hesitation to attempt to insert the O-cell through the grouted pile prevented the implementation of this technology. Techniques utilized to evaluate and ensure proper placement of the O-cell at the desired depth within the grouted pile are presented. A brief description of four (4) high-rise building projects, which required the use of deep foundation elements to limit settlements are discussed. Unique geologic conditions, which allow the use of large diameter, deep, high-capacity piles are also presented. Schematics of the O-cell load test setup, the results of the O-cell load tests, and load distributions along the pile shaft are also presented and discussed.

DEVELOPMENT BOOM AND HIGH-RISE PROJECTS IN SOUTHEAST FLORIDA

The downtown areas of Miami, Fort Lauderdale, and other areas of South Florida are undergoing a development boom primarily within the urban areas of the downtown cities and the beaches. The development boom is associated primarily with the construction of high-rise buildings ranging from 15 stories to as tall as 75 stories in height. Recent publications in local newspapers in Miami-Dade County have indicated that approximately 100 high-rise, condominiums, office, hotel, and mixed-use buildings are either under construction or are in the planning phases for development in the near future.

Four high-rise building projects in the downtown Miami area are subsequently discussed relative to the implementation of O-cell load testing of ACIP piles. All four of these projects are in the early phases of development and building renderings of three of the four projects are shown in Figure 1 to illustrate the magnitude of the high-rise construction for the subject projects.

GEOLOGIC SETTING



Figure 1 – Typical High-Rise Projects

The South Florida area consists of sedimentary geologic formations. The uppermost geologic strata that most closely resemble rock-like material include the Miami Formation and the Fort Thompson Formation. Within the downtown area of Miami, the typical subsurface conditions consist of a thin deposit of fill, sand or shore deposits, followed by soft oolitic limestone of the Miami Formation. Beneath this are layers of sand of varying density intermixed and interbedded with the soft sedimentary rock formations of the Fort Thompson Formation including: limestones, sandstones, cemented sands and shells. The rock formations of the South Florida area are considered to be soft in geologic terms as most of the material above 80 to 90 feet (24 – 27m) can be conventionally sampled with split-spoon sampling techniques. The underlying subsurface material can also be split-spoon sampled; however, refusal type Standard Penetration Resistances are commonly recorded. Rock coring within this deeper material with conventional NX core barrels yields poor results and utilizing larger 4-inch (100mm) diameter core barrels allows for

increased recoveries. A generalized geologic profile typical to the downtown Miami area is shown in Figure 2.

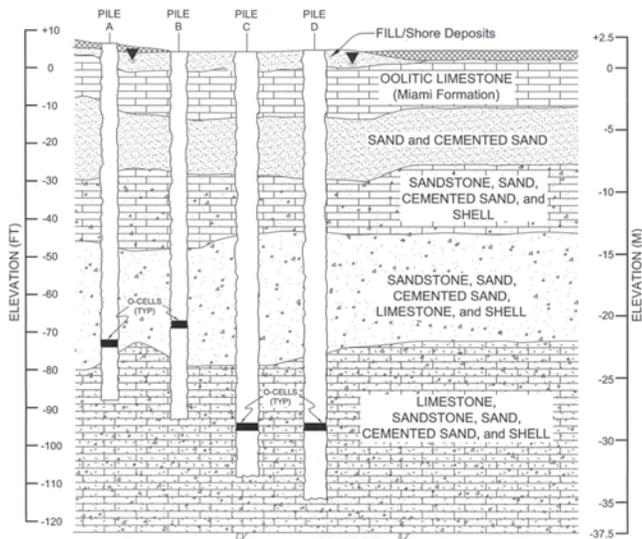


Figure 2 – Geological Profile

ACIP PILE AND O-CELL INSTALLATION/ LOAD TESTING PROCESS

The evolution of the local ACIP piling contractor's equipment has allowed the installation of 24-inch and 30-inch (610mm and 760mm) diameter ACIP piles commonly to depths of 125 feet (38m) and up to as deep as 150 feet (46m). See Figure 3.



Figure 3 – ACIP Piling Installation

Typical individual pile design capacities are on the order of 450 to 700 tons (410 to 635 tonnes) utilizing sand/cement grout having compressive strengths ranging from 7,000 to 8,000 lbs/in² (48 to 55 MPa). For all of the O-cell installations, a fluidifier was utilized to maintain the grout in a fluid state to facilitate insertion of the fully instrumented reinforcing cage with O-cell

assembly (flow cone rate of approximately 15 seconds). Full-length reinforcing steel cages are standard to resist the high compressive, tensile and lateral loads as well as to serve as a supplemental quality control verification method.

To maintain standard ACIP construction methods, the O-cell/cage assembly must be ready to insert as soon as the auger has completed the grouting process. Total installation time is typically less than 60 seconds, even for the 150 foot (45m+) piles. The O-cell/reinforcement cage assembly is inserted into the cement grout in the same manner as a standard ACIP cage assembly – e.g. rebar, Dywidag bar or other configuration – such as a small H-pile. Prior to hoisting the reinforcement cage, complete assembly of the O-cell configuration within the cage is performed and typically takes about 2 hours for the placement of all hoses, telltale pipes and the welding of the O-cell to the cage. It was recognized very early in the process that adaptive measures had to be taken to not alter the standard installation procedure of pile construction by the contractor in any significant way.

Performance of a bi-directional O-cell load test within an ACIP pile for the subject high-rise projects involved insertion of an embedded O-cell jack welded to plates, which were attached to full length instrumented reinforcing cages. The ACIP test piles are formed by drilling to the required depth using a hollow stem continuous flight auger. After attaining the required embedment into a specified stratum and reaching the required depth, fluid grout (flow cone rate of approximately 15 seconds) is then pumped through the hollow stem of the auger. After establishing a specified head of grout above the tip of the auger, the auger is then slowly and steadily withdrawn while maintaining a positive auger rotation and while continuously pumping grout through the stem of the auger. A controlled rate of auger extraction and manually calculated pumped volume of grout is maintained throughout the grouting process. Computerized, automated monitoring equipment (CAME) to infer grout volume pumped per incremental auger withdrawal was utilized as a supplemental quality control tool. For the larger diameter ACIP piles, cross-hole sonic logging was also utilized as a supplemental quality control/integrity verification tool. The instrumented, full, length, reinforcing cage with the O-cell attached was then inserted into the fluid grout filled pile. Maintaining and providing a fluid grout mix is essential to allow insertion of the reinforcing steel and attached O-cell. See Figure 4 & 5.

The minimum annulus between the O-cell and pile wall has not exceeded the specified “cover” of any pile to date, with typical grout cover specified at 3” (75mm). However, the ratio of the O-cell diameter vs. shaft diameter has changed allowing for higher applied loads. Initial concern of installation



Figure 4 – O-cell Installed in Rebar Cage



Figure 5 – Installing Rebar Cage in Test Pile

problems kept the ratio (O-cell diameter/Shaft diameter or O_{dia}/S_{dia}) at approximately 0.5 (e.g. 13 inch (325 mm) diameter O-cell in a 24 inch (600 mm) diameter shaft). The O_{dia}/S_{dia} ratio has been increased to 0.7 having installed a 21 inch (525 mm) O-cell into a 30 inch (750 mm) diameter ACIP pile* (*This particular shaft was tested to greater than 3000 tons (30 MN) of the equivalent top load).

The O-cell is a hydraulically driven, calibrated, sacrificial jacking device installed within the foundation unit, utilizing the end bearing and side shear resistance of the pile to resist applied load. By virtue of its installation within the foundation unit, the O-cell load test is not restricted by the limits of overhead structural beams and tie-down/anchor/reaction piles. Instead, the O-cell derives all reaction from the soil and/or rock system. End bearing and lower side shear provide reaction for the upper side shear portions of the O-cell load test and upper side shear provides reaction for the end bearing and lower side shear portion of the load test.

Instrumentation is utilized as necessary to determine load distribution along the foundation unit’s shaft, movement of the tip of the shaft and movement of the head of the foundation unit. Such instrumentation includes: vibrating wire “sister bar” strain gauges, LVWDT’s and telltales as well as remote

compression devices. Applied loads are determined utilizing pre-calibrated bourdon pressure gauges.

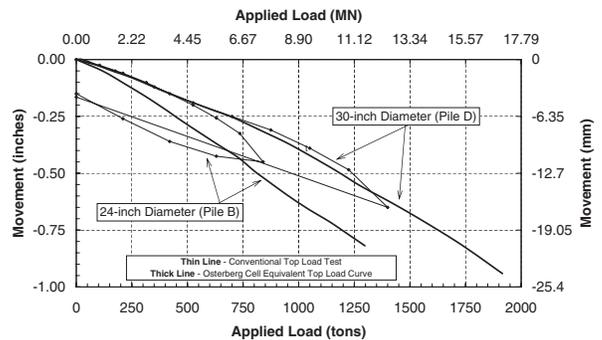
SUMMARY OF O-CELL LOAD TEST RESULTS

The following table provides a summary of the pertinent test pile information, maximum O-cell test load and measured O-cell expansion as well as a comparison of the O-cell test results with conventional top load tests performed at the same project site.

Graphical representations of the load test results for both the conventional top load tests and the O-cell tests are shown in Figures 6 and 7.

	PILE A	PILE B	PILE C	PILE D
ACIP Pile Diameter	24-inch (600 mm)	24-inch (600 mm)	30-inch (750 mm)	30-inch (750 mm)
Pile Length	95 ft (29 m)	99 ft (30 m)	117 ft (36 m)	124 ft (38 m)
O-cell Diameter	13-inch (325 mm)	13-inch (325 mm)	16-inch (400 mm)	16-inch (400 mm)
Maximum Bi-Directional Test Load	1,273 Kips (5.66 MN)	1,322 Kips (5.88 MN)	1,855 Kips (8.25 MN)	2,004 Kips (8.9 MN)
Equivalent Top Load	2,546 Kips (11.32 MN)	2,644 Kips (11.76 MN)	3,710 Kips (16.5 MN)	4,008 Kips (17.8 MN)
Maximum O-cell Expansion	0.25 inch (6.25 mm)	0.36 inch (11.25 mm)	0.16 inch (4 mm)	0.33 inch (8.25 mm)
Maximum Conventional Compression Top Load	840 tons (7.47 MN)	840 tons (7.47 MN)	N/A	1400 tons (12.46 MN)
Maximum Deflection During Top Load Test	0.23 inch (5.75 mm)	0.45 inch (11.25 mm)	N/A	0.67 inch (16.75 mm)

CONVENTIONAL TOP LOAD AND OSTERBERG CELL TEST CURVES FOR 24-INCH AND 30-INCH ACIP PILES B & D



THIN LINE - Conventional Top Load Test
THICK LINE - Osterberg Cell Equivalent Top Load Curve

Figure 6

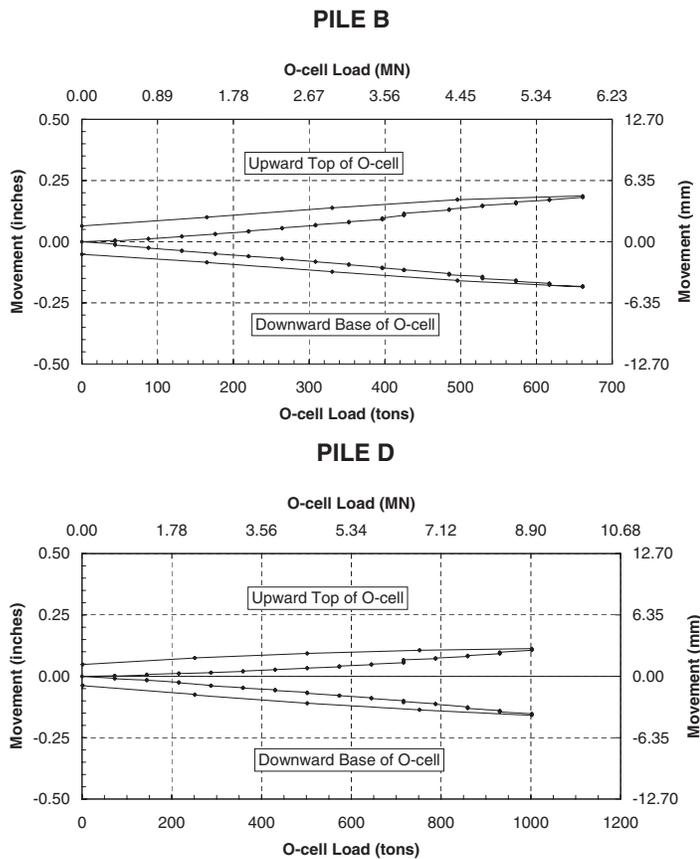


Figure 7

The data from the strain gauges within the conventional top load test indicates that less than 10% of the maximum test load is transferred to the top of the Limestone, Sandstone, Sand and Cemented Sand and Shell stratum encountered at approximately elev. -80 feet (-24m). The data from the strain gauges within the O-cell load tests indicate variations in the mobilized side shear within the Limestone, Sandstone, Sand and Cemented Sand and Shell stratum. This is common due to the variable degree of cementation in the bearing materials. Careful evaluation, local experience, and engineering judgment are required to properly interpret unit side shear values at various depths due to this effect.

The standard top load tests and the O-cell load tests cannot be directly compared as the load-tested piles mobilize skin frictional resistances within different zones of subsurface materials. Interpretation of mobilized skin frictional resistances during top load testing within the more near surface zones of material is necessary to facilitate more accurate generation of equivalent top load test curves from the full-scale O-cell test.

O-cells can be integrated into production piles, but to date this has not been attempted in the ACIP pile realm. Production pile

testing (primarily in drilled shafts/caissons) has been a hallmark of the Osterberg test method, with assembly and test procedures modified to maintain pile integrity. Post test procedures amount to grouting the O-cell (via the pressure hoses) and additional grouting of any annular space created in the fracture plane of the O-cell. (via the telltale pipes).

Based on the results of over a dozen successful O-cell tests in ACIP piles, pile integrity does not seem to have been compromised from a test performance perspective. More than 80% of the ACIP/O-cell tests to date have reached or exceeded 3 times original design loads without reaching ultimate side shear or end bearing. Total movements measured in Figure 7 have been the norm rather than the exception.

CONCLUSION

From an engineering standpoint, the implementation of full-scale O-cell load testing of ACIP piles has allowed the load carrying capacity of full-scale piles installed into deep sedimentary rock layers to be analyzed and evaluated. This information obtained from O-cell testing assists in understanding and predicting the load deformation characteristics of foundation systems for high-rise buildings. The use of O-cell load testing allows the installation of large, high capacity ACIP piles and verification load testing to be performed, which eliminates the need to perform large scale, difficult top load tests. Recently, O-cell load testing has been accepted solely by local regulatory agencies to substantiate the foundation design for high-rise buildings provided the requirements of the local code with respect to load testing increments and durations are met.

Great strides were taken to maintain the standard operating procedures of ACIP pile construction and installation. Some modifications were necessary in the installation process and assembly of the O-cell in order to integrate this unique test method into an existing construction technique.

References

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