World record bi-directional load testing of CFA piles

Record du monde : essais de chargement bi-directionnel sur pieux forés à la tarière

M. England

LOADTEST, United Kingdom.

ABSTRACT

Recent application of Osterberg cell® (O-cell®) bi-directional load testing technology to continuous-flight-auger pile (CFA) or augered cast-in-place pile (ACIP) industry, particularly in South Florida, has resulted in some record breaking results. The unique ground conditions in and around the Miami area, together with advances in the equipment used for their installation, have allowed a thriving piling industry to be developed using large diameter, deep, high capacity CFA piles.

The O-cell, which has traditionally been thought of as only applicable to load testing of bored piles and barrettes, has been developed for efficient and effective use with the continuous-flight-auger pile (CFA). The O-cell is a purpose built, hydraulically driven sacrificial jack, which is installed with appropriate additional instrumentation within the pile itself, at a level where equal pile capacity is expected above and below. Bi-directional static load tests have some key advantages over “top-down” loading methods.

Some case histories are presented and discussed, together with details of individual projects and results obtained for CFA piles and subsequent development to apply greater loads. The pile capacities of some of these CFA schemes are significantly greater than those typically designed for Europe and the loads mobilised in some of the bi-directional tests, to over 40MN, are well in excess of what can be applied using standard “top-down” loading methods.

RÉSUMÉ

La méthode de chargement bi-directionnel avec des cellules Osterberg® (O-cell®) a été récemment adaptée pour être utilisable dans des pieux forés à la tarière continue de gros diamètre, de grande profondeur et de capacité importante. Plusieurs essais sont présentés et analysés en détail. Les charges mobilisées durant les essais bi-directionnels sur les pieux forés à la tarière continue ont dépassé les 40MN ; cette charge est difficile à atteindre avec les méthodes classiques d’essais de chargement statique.

Keywords: O-cell, CFA, ACIP, bi-directional static load test.

1 INTRODUCTION

This paper discusses the recent implementation of Osterberg cell® embedded jack (O-Cell) load testing technology to the continuous flight auger (CFA) piling industry in the USA and in particular the South Florida area. Since September of 2004, nearly 30 O-cell tests, including one multi-level test, have been performed in large CFA piles of lengths to over 50m in depth.

Concerns often exist regarding the insertion of a reinforcing cage to full depth and these reservations are augmented when thinking about also plunging an O-cell arrangement through the grouted pile. This appeared to prevent the implementation of bi-directional testing. Techniques utilized to evaluate and ensure proper placement of the O-Cell at the desired depth within the grouted pile are presented.

A brief outline of some high-rise building projects, which required the use of deep foundation elements to limit settlements are discussed and were instrumental in the initial development of bi-directional testing. The unique geological conditions, which allow the use of large diameter, deep, high capacity CFA piles is also presented together with a short account of some of the recent developments and the test loads that have been achieved.

2 HIGH-RISE PROJECTS IN SOUTHEAST FLORIDA

The downtown areas of Miami, Fort Lauderdale, and other areas of South Florida have been undergoing a development boom primarily within the urban areas of the downtown cities and the beaches. This rapid growth has been associated primarily with the construction of high-rise buildings ranging from 15 storeys to as tall as 75 storeys in height. Recent publications in local newspapers in Miami-Dade County have indicated that approximately 100 high-rise, condominium, 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 CFA piles.

3 GEOLOGICAL PROFILE/PILE DESIGN

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, 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 in the South Florida area are considered to be soft in geotechnical terms as most of the material above a depth of 24 – 27m can be conventionally sampled with split-spoon sampling techniques. The underlying subsurface material can also be split-spoon sampled; however, Standard Penetration Resistances commonly record refusal. Rock coring within this deeper material with conventional NX core barrels yields poor results and utilizing larger 100mm diameter core barrels allows for increased recoveries. A generalized geological profile is shown in Figure 1.

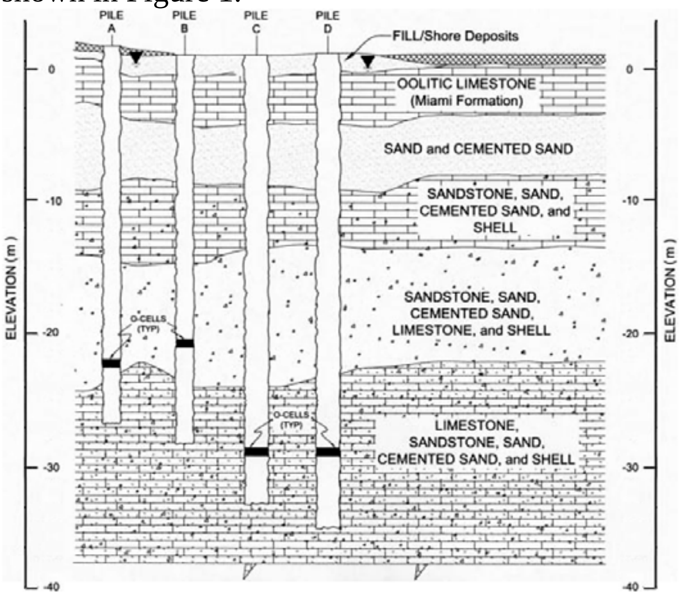

Figure 1 – Geological Profile

General concerns about piles being founded in the oolitic limestone prompted geotechnical engineers to aim for the sandstone layer, and more recently reports of this second layer showing signs of settlement have prompted the installation of piles in the limestone (starting at around 25 - 35m).

The result is that some of the pile designs have been driven by geotechnical concerns and not just by structural loadings from the building.

Consequently, with these deep piles, their capacities have been well in excess of the design requirements and with such high loads would have been a challenge to test by top-down loading methods.

4 CFA PILE AND O-CELL INSTALLATION /LOAD TESTING PROCESS

The evolution of the local CFA piling contractor's equipment has allowed the regular installation of 600 mm and 750 mm diameter CFA piles to depths of 38m and as deep as 54m. See Figure 2.

Typical individual CFA pile design capacities have been in the order of approximately 5 MN utilizing sand/cement grout having compressive strengths ranging from 48 to 55 MPa. For all of the O-cell installations, a fluidizer was utilized to maintain the grout in a workable state and 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.

To maintain standard CFA construction methods, the O-cell/cage assembly has been ready to insert as soon as the auger has completed the grouting process. Typical installation time for the instrumented cages has been just a few minutes, even for the >45m piles. The O-cell/reinforcement cage assembly was inserted into the cement grout in the same manner as a standard CFA cage assembly – e.g. rebar, Dywidag bar or other configuration - such as a small steel H-section. Prior to lifting the reinforcement cage, the assembly of the O-cell arrangement and instrumentation within the cage was performed and taking as little as 2 hours for the placement of all hoses, telltale pipes and the welding of the O-cell to the cage.

Figure 2: 50m cage ready for insertion into pile.

The CFA piles are formed by drilling to the required depth using a hollow stem continuous flight auger, normally using a single string of augers. The grout delivery line is then pressurised and 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 is used, such that the volume covered is in excess of the volume of grout delivered. Computerized, automated monitoring equipment to infer grout volume pumped per incremental auger withdrawal was utilized as a supplemental quality control tool. For the larger diameter CFA piles, cross-hole sonic logging was also utilized as an additional 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 has been essential to allow insertion of the reinforcing steel and attached O-Cell.

The specified "cover" of 75 mm has been maintained on all the pile tests reported. However, the ratio of the O-cell diameter to shaft diameter (O_{dia}/S_{dia}) has been changing to allow for higher applied test loads. Initial concern and in the interest of avoiding installation difficulties suggested keeping the ratio low and at approximately 0.5 (e.g. 330 mm diameter O-cell in a 600 mm diameter pile). The O_{dia}/S_{dia} ratio has been steadily increased to 0.7 having installed a 540 mm O-cell into a 750 mm diameter CFA pile and a 660 mm O-cell in a nominal 900 mm diameter pile (both these piles were tested to > 30 MN).

The connection to the reinforcing cage has been modified slightly from the use of 50mm thick bearing plates mounted either side of the O-cell, to the use of a castellation arrangement which allow easy connection to the reinforcing bars and minimises the profile to aid insertion. As illustrated in Figure 3.

Figure 3: arrangement for connection to the reinforcing cage.

The development and use of larger diameter O-cells in CFA piles has been done with caution and by evaluation of any installation difficulties by using a dummy O-cell of similar diameter and volume mounted on the reinforcing cage and tested in an adjacent pile; this also allowed the fluidity of grout/concrete mix to be assessed.

The O-cell is a hydraulically driven, calibrated, sacrificial jacking device installed within the foundation unit, utilizing the end bearing and frictional resistance of the pile to resist the 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 anchor reaction piles nor kentledge. Instead, bi-directional testing derives all reaction from the soil and/or rock system around the pile itself. End bearing and lower skin friction provide reaction for the upper skin friction and the upper skin friction provides simultaneous reaction for the end bearing and lower skin friction portion of the pile during the load test, a schematic illustrating the general concept is shown in Figure 4.

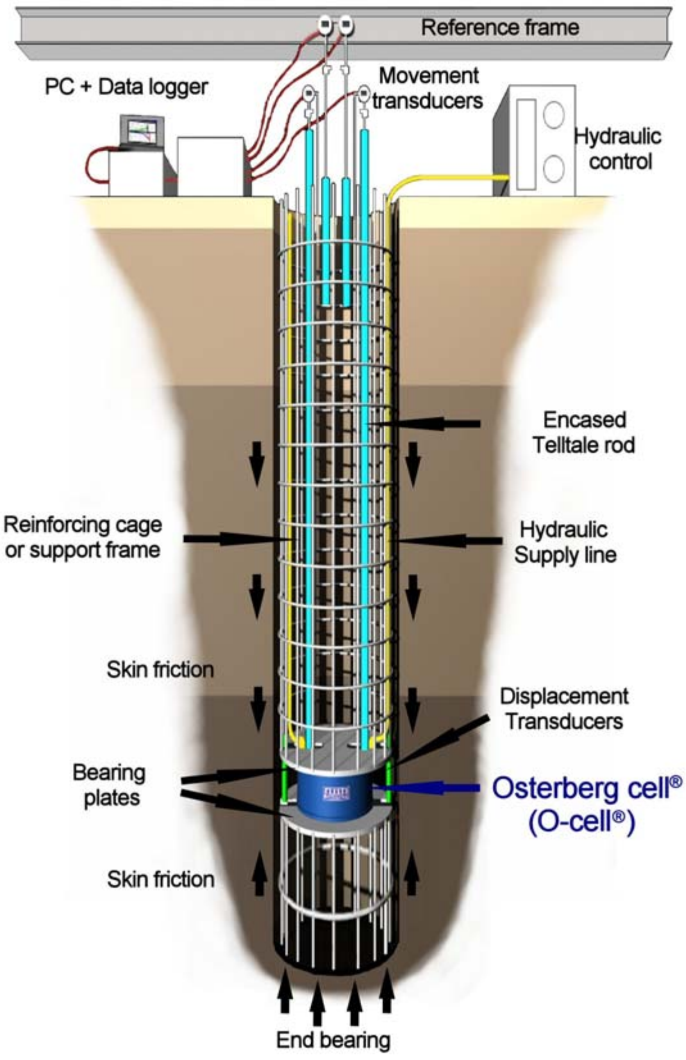

Figure 4: Schematic of O-cell testing

Instrumentation has been utilized as necessary to determine load distribution along the foundation unit, movement of the tip of the pile and movement of the pile head. Such instrumentation includes: vibrating wire "sister bar" strain gauges, LVDTs and telltales. Applied loads have been determined utilizing pre-calibrated pressure gauges.

5 SUMMARY OF O-CELL TEST RESULTS

Table 1 provides a summary of the pertinent test pile information on 4 of the early "large CFA O-cell tests", maximum O-cell test load, causing O-cell expansion of less than 10 mm. Pile identifications correspond to the penetrations illustrated in Figure 1.

Data from the strain gauges in top loaded test piles indicated 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 24m deep. The data from the strain gauges within the O-cell load test piles indicate variations in the mobilized friction 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 were required to interpret unit skin friction values at various depths due to this effect.

Table 1.- Initial large CFA O-cell tests

CFA Piles [2004/5]	**PILE A**	**PILE B**	**PILE C**	**PILE D**
Pile Diameter [mm]	600	600	750	750
Pile Length [m]	29	30	36	38
O-cell Diameter [mm]	330	330	405	405
Maximum Bi-Directional Test Load [MN]	5.66	5.88	8.25	8.9
Mobilised Load [MN]	11.32	11.76	16.5	17.8

The top loaded tests results and the O-cell load tests results cannot be directly compared as these piles mobilized frictional resistances within different zones of subsurface materials. Interpretation of mobilized skin frictional resistances during top load testing within the near surface zones helped facilitate more accurate generation of equivalent top load test curves from the full-scale O-cell test.

To overcome the limitation of not being able to mobilise much of the total capacity of the test piles, higher loads have been applied using single level O-cell arrangements and a multilevel system:

5.1 *Single level O-cell arrangement:*

Since the data presented in Table 1, eight CFA piles have been tested bi-directionally using the larger 540 mm O-cells, mobilising a load of over 20MN at rated O-cell capacity and by over-pressurising the O-cell over 30MN has been achieved.

Figure 5 illustrates a 660 mm O-cell arrangement about to be assembled to the upper cage for insertion in a 900 mm CFA test pile. Total pile length constructed was 35 m with the O-cell set at approximately 30 m.

The test was performed applying up to 16MN in each direction, with a resulting O-cell expansion of approximately 13 mm.

Figure 5: A 660mm O-cell about to be integrated into upper section of reinforcing cage.

5.2 *Multilevel O-cell CFA test*

A method for mobilising greater capacity with a pile is to have more than one level of O-cells. The multilevel arrangement effectively divides the pile into more than two separate components and each of these can be mobilised in turn. The O-cells can be arranged at specific levels within the pile to assess the behaviour of particular soil layers.

In practice, a multilevel O-cell test is performed in stages, typically mobilising the bottom element initially, then the mid section, and by closing the lower O-cell arrangement hydraulically, sufficient reaction is generated to mobilise the upper section of the pile. The different phases of the testing are shown graphically in Figure 6.

In a specific example from Miami, two 540 mm O-cell were inserted in a 900 mm diameter, 36.3 m deep CFA pile and the O-cell levels were close to the bottom, at 31 m and 35 m deep.

In this multilevel CFA pile test a total of 46 MN was mobilised.

6 FUTURE DEVELOPMENTS

Table 2 notes the progress made in terms of size and loads mobilized with bi-directional testing of CFA piles.

Table 2.- Recent large CFA O-cell tests [2006]

Pile Diameter [mm]	750	750	900	900
Pile Length [m]	37	40	35	36
O-cell Diameter [mm]	540	540	660	2x540
Mobilised Load [MN]	25	32	32	46

O-cells have been regularly used in bored working piles, but at the time of reporting, this has not been attempted in CFA piles. Post test grouting of the O-cell (via the hydraulic hoses) and additional grouting of the annular space created in the fracture plane of the O-cell (via the telltale pipes) reinstates the integrity of the pile.

Based on the results of over thirty successful O-cell tests in CFA piles, pile integrity does not seem to have been compromised from a test performance perspective. More than 80% of the CFA/O-cell tests to date have reached or exceeded 3 times original design loads without reaching ultimate skin friction or end bearing.

7 OTHER CFA PROJECTS

The success of O-cell testing in CFA piles in Florida has lead to the technique being adopted in other states of the USA. Projects in Wisconsin, Minnesota and Indiana have completed tests in 450 mm and 600 mm diameter CFA piles and it is hoped that other States will follow the lead set in Florida now that any reservations regarding the use of O-cell testing techniques in CFA piles has been dispelled. The continued increase in CFA piling across the USA will create further opportunities for O-cell testing and development in the future.

Where necessary and particularly with concrete CFA piles, it might be advisable to consider the use of a dummy arrangement to evaluate any difficulties with the O-cell/cage insertion or consider the use of grout instead for European CFA O-cell test piles.

8 CONCLUSION

The application of O-cell load testing of CFA piles has allowed the load carrying capacity of 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. The use of the O-cell allows load testing of large, high capacity CFA piles which eliminates the need to perform large scale, difficult top-down load tests.

The standard CFA construction procedures has not been interrupted nor disrupted by the installation of the O-cell and instrumentation. Only minor modifications have been necessary to the assembly of the O-cell.

The successful testing programs undertaken in South-West Florida have given contractors and design engineers confidence to use the technique of bi-directional O-cells testing in CFA piles and have mobilised loads otherwise unattainable with top-down loading methods.

ACKNOWLEDGEMENTS

The author wishes to thank Langan Engineering and Environmental Services, Inc. for their vision to employ state of the art technologies for pushing the boundaries of static load testing, and to HJ Foundation Inc. of Miami for their expert and successful implementation of some of the largest CFA piles in the world.

REFERENCES

Osterberg, J.O. (1994), *Recent Advances in Load Testing Driven Piles and Drilled Shafts using the Osterberg Load Cell Method* Presented: Illinois A.S.C.E. Geotechnical Lecture Series.

Schmertmann, J.H., Hayes, J.A. (1997), *The Osterberg Cell and Bored Pile Testing*, Proceedings: 3rd International Geotechnical Engineering Conference, Cairo University, Cairo, Egypt. Pp. 139-166

England, M (2003) *Bidirectional static load testing – State of the art*, International seminar, Deep foundations on Bored and Auger Piles, BAPIV Ghent, Millpress, June pp309-313.

England, M , Cheesman, P (2006) *Recent experiences with bi-directional static load testing*, 10th International conference on Piling and Deep Foundations DFI EFFC Amsterdam, June, pp 652-660.

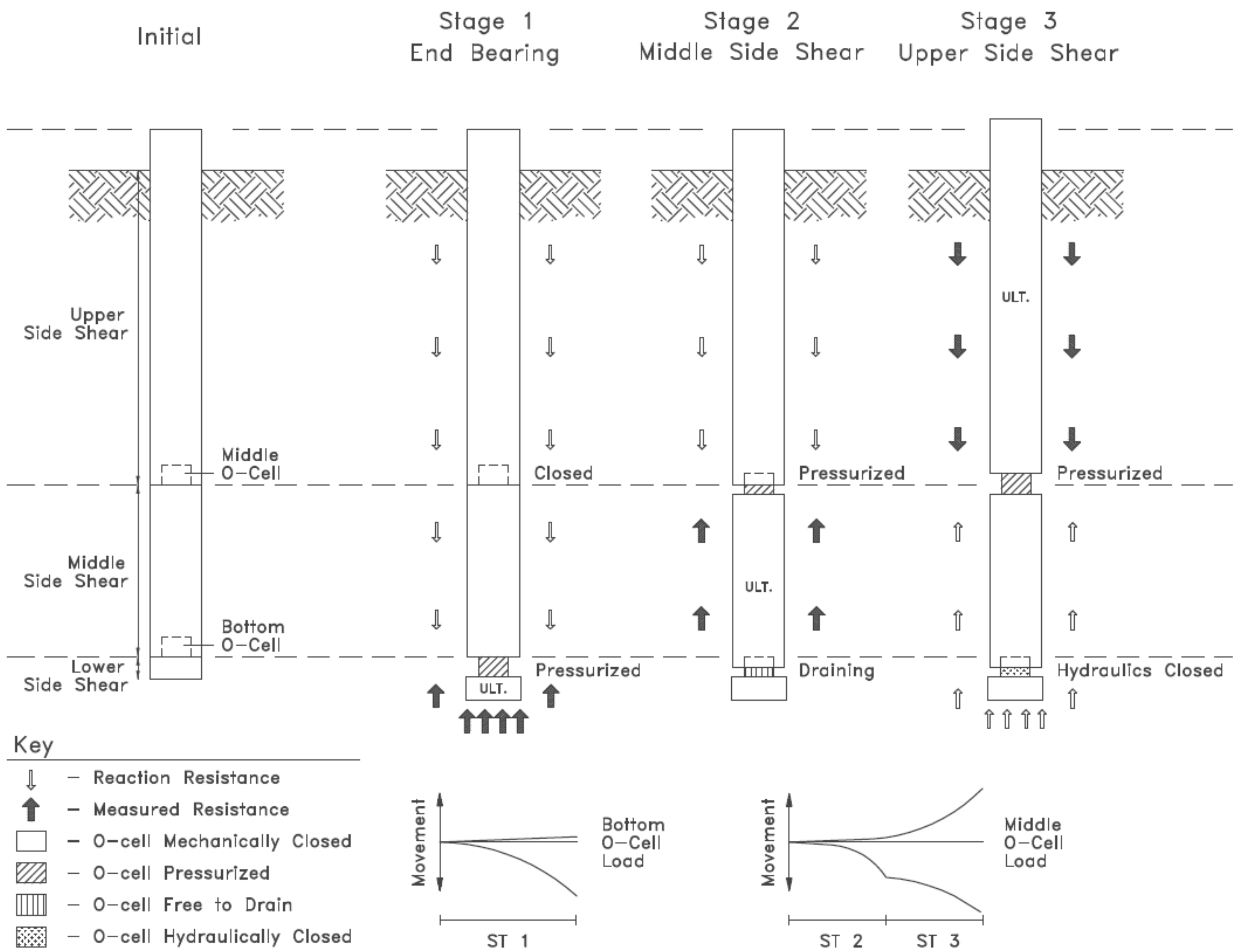

Figure 6: Multi-level O-cell staged testing