

## DESIGN BENEFITS OF BI-DIRECTIONAL LOAD TESTING OF BARRETTES.

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Barrettes are normally used in the construction of structures with high foundation loadings, especially where there is a small construction footprint such as very high rise buildings. As construction within the world's busiest cities becomes more difficult due to space restrictions, barrette foundations are being seen as a necessary and cost effective alternative to large diameter bored piles. However, the consequences of choosing the wrong design parameters could neutralise or even reverse any cost savings. The outcome of incorrect design parameters in terms of settlement and load bearing capacity could be even more dramatic.

Until the introduction of bi-directional testing with the Osterberg cell, the static load testing of barrettes as a foundation element was generally restricted to loads below 40MN by traditional top-down loading methods or by the use of smaller scale loading of piles in the same material to derive capacity parameters used for the design. Today, evidence is being accumulated which casts some doubt on the accuracy and relevance of the values obtained from such reduced scale testing, Hayes (2008). More often, a conservative approach by designers is taken, using the soil tests results from site investigation and applying a high factor of safety. The penalty for using a conservative design approach is the increase in the cost of the foundation construction.

The use of bi-directional testing by placement of sacrificial loading elements [O-cell<sup>®</sup>] within the structure of the barrette profile, without the need for an external reaction system, can allow direct appraisal of both the skin friction and end bearing values. Bi-directional testing has been performed on many barrettes worldwide, on a variety of sizes, cross sections and lengths, with top down equivalent (or gross) loads of up to 220MN being mobilised.

The results obtained from the testing has often lead to a reappraisal of the original design, both on unit skin friction values and on estimated end bearing capacity.

As the popularity of the technique for static load testing barrettes is becoming more widespread around the world and applied to numerous interesting projects, some recent case histories are presented along with some noteworthy observations.

### **INTRODUCTION**

O-cell<sup>®</sup> bi-directional testing technology has enhanced the full scale static load testing capabilities of barrettes worldwide.

By the use of a hydraulically driven, purpose built, calibrated, sacrificial jacking device, (the O-cell<sup>®</sup>), installed within the pile/barrette shaft, the resistance data is automatically separated. In effect, two full scale static load tests are performed simultaneously, working in opposite directions, upwards against skin friction and down-wards, against combined skin friction and end-bearing.

Installing the testing apparatus within the pile/barrette shaft means the bi-directional test is not restricted by the limits of overhead structural beams, kentledge weight or reaction piles. The many associated difficulties of conventional top down testing methods are eliminated, and the maximum test load limited only by the capacity of the pile/barrette (England, M. 2003).

This method of testing foundations has entered a new found domain with testing of rectangular deep foundations in several key locations across the world and taking the load testing capacity of barrettes where it was almost impossible to go before. Rectangular sections from 2.5 m to 7 m in length and 'T' shaped sections have been tested with mobilised loads of up to 220 MN.

Testing of barrettes has previously been either ignored or loading arrangements have not been sufficient to test to the full capacity. Reaction systems normally require anchors, which necessitates the need to mobilise a separate piling rig to construct, or large kentledge constructions which are both expensive to erect and have proved dangerous in their use. In most areas of the world, reaction systems to provide traditional top down loads in excess of 40 MN are almost non-existent, and beyond 65 MN unheard of; (Thasnanipan, N. et Al 2001); whereas, O-cell bi-directional testing can easily provide these test

loads and substantially more without the need for external reaction arrangements.

Bi-directional testing has been employed on several barrette projects and has been developed into an efficient, cost effective method for full scale static load testing of barrettes by using the patented bi-directional O-cell testing technique.

Some examples of barrettes recently tested in St. Petersburg, Dubai, Milan, Kiev, Bucharest, Vietnam, Singapore and Las Vegas covering a wide range of mobilised loads, sizes and shapes are outlined. As more and more foundations utilise barrette construction for their foundation design, it is clear that bi-directional testing will play a key role in future barrette foundation developments.

### **Single Level Bi-Directional Testing**

#### **St Petersburg, Russian Federation: Okhta Centre**

The historic Russian city of St Petersburg is planned to be the location of the new headquarters for Gazprom, owner of around 16% of the world's gas reserves. Not all the inhabitants of this historic city dubbed 'The Venice of the North' are in favour of the building of such a tall tower. It was therefore important to the owners that any project undertaken would be sensitive to the views of some of the local people.



Figure 1 Artists Impression

A competition to design the new building was run with many innovative and spectacular designs entered.

The eventual winner for the 396 m Okhta Tower and Centre, Figure 1, reports that as well as being the tallest tower to be constructed in Europe, will also be among the greenest. According to RMJM, structural engineers, this will be 'one of the most environmentally sustainable high rise buildings in the world'. This will be some feat for a tower that will have to stave off the fierce minus 30 degree C Russian winters.

Building the tallest tower in Europe brings great challenges for the designers, not only on the Eco front but also for those involved in the foundation design. One of the main challenges would be the design and testing the foundation elements to loads unachievable by traditional top down load testing.

A solution investigated for the foundations was to employ barrettes instead of foundation piles.

St Petersburg proved the ideal location to further demonstrate this method to high loadings and to compare the results with a top down test on the same barrette to lower loads. Bovis Lend Lease together with Ramboll Whitbybird consultants designed the testing programme to do just this.



Figure 2 Reaction beam set-up for traditional 30 MN top down test

One barrette of 3300 mm x 1000 mm and 63 metres deep was chosen for the initial preliminary testing on this project. The barrette would be tested by both traditional top down static load testing to 30 MN and by bi-directional techniques using O-cell technology with a test capacity of 90 MN.

Loading of the barrette using a top down method required the manufacture and construction of a

reaction system capable of providing more than the required 30 MN as reaction, shown in Figure 2. This involved placement of anchor bars around the barrette location as anchorage of the steel reaction frame setup. It also required the construction of a zero shear zone from ground level to a depth of 9.4 m. This was achieved by post-construction drilling around the barrette head to form a void. Under normal circumstances, using bi-directional testing methods, this could be achieved very simply by casting the concrete level lower and only up to the level of interest.

In contrast to the significant reaction system required for a traditional top down loading, a feature of bi-directional testing is the inherent safety of the system by using the barrette shaft and end bearing as the reaction for the test.



Figure 3. -O-cell assembly installed safely within the barrette steelwork during construction.

The bi-directional loading assembly employed three 660 mm O-cells, see Figure 3, providing a loading capacity greater than 90 MN, was placed within the barrette steelwork during construction by Foundation Engineers, Geoizol.

The geotechnical properties of the Vendian Clay substrata were unknown. It was, therefore, very important to the foundation design that as much information as possible was gained by the preliminary testing and several levels of strain gauges were placed in the barrette and monitored during the testing using both methods of loading to allow detailed information on shaft unit friction values to be determined.

Since constructing a reaction frame and anchor system to allow higher loading from the top down method above 30 MN would have proved almost impossible given the soil conditions around the test area, the results from the bi-directional test were invaluable and provided information that would not otherwise have been obtained.

The results from the testing would be used to optimise the design. Additional bi-directional testing, similar to that illustrated in Figure 4, will

be performed to further validate the results of the initial testing on the new design.



Figure 4 Barrette head under bi-directional static load testing

The correlation between the initial 30 MN top-down test and the subsequent bi-directional testing was excellent. (In Figure 5, both sets of results from the two static loading methods are compared; the 30MN traditional top down loading, and the bi-directional test results converted into equivalent barrette head movement using two methods, sum of the measured and the Cemsolve® analysis and Cemset® load-settlement prediction (sum of the modelled) (as described by Fleming, 1992 and England, 2007).

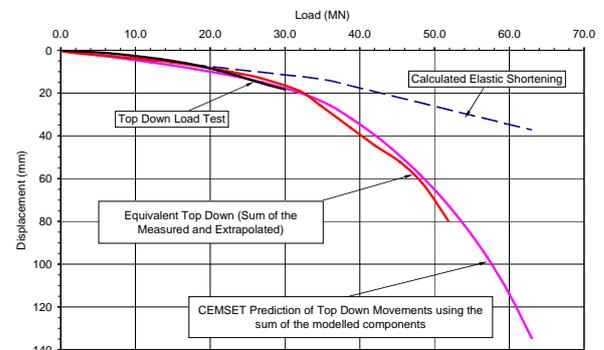


Figure 5.- Comparison between top down and bi-directional static load testing results

### **Kiev, Ukraine: AOB Tower**

The scope of the test was to verify and optimise the design of the element with limited penetration into the sand layer through various clay layers.

The load obtained on the 2800 mm x 1200 mm, 60 metre deep barrette in Kiev was unachievable by other means. Testing for the AOB Tower in Kiev achieved a test load of 44 MN in each direction giving a net mobilised load of 85.5 MN on the test barrette using three 660 mm O-cells as illustrated in Figure 6 close to the panel toe.



Figure 6.-Installation of barrette cage in the panel.

Strain gauges were installed within the barrette shaft, for evaluation of skin friction parameters. It is understood that these will also be monitored long term, allowing the measurements to be used for post construction testing as an additional benefit.

It was chosen to use two tremie pipes (Figure 7) for the concreting of the panel and subsequent grouting at the base to ensure good connection to the undisturbed soil below the panel to reveal the underlying end bearing behaviour.



Figure 7.-placement of two tremie pipes for concreting.

As a result of the test programme, the total length of the barrettes for the structure could be reduced.

## **'T' Shape and Wall Barrettes**

### **Vietnam: Pearl Phuong Nam Towers, Hanoi**

Under the instruction of the consultancy company of the Civil Engineering Department at Hanoi University, two barrettes of different size were tested on this site. One 1.2 m x 7.0 m rectangular barrette was tested along with a barrette of 'T' shaped profile.

### **'T' Barrette**

The 2.8 m x 4.0 m 'T' shaped barrette was a first the first panel of this shape to be tested using the bi-directional testing technique. The soil strata consisted primarily of sand and stiff clay underlain by dense to very dense sand and gravel. Figure 8 shows the O-cell assembly mounted in the purpose build bearing plates within the reinforcing cage.

During construction concrete was supplied simultaneously to both 'arms' of the barrette by the placement of twin tremie pipes within the cage sections, as shown in Figure 8, to allow even and distributed delivery of concrete during construction.

The loading assembly consisted of 4 number 510 mm diameter O-cells located 12.60 metres above the base of the 48.55 m long barrette. This allowed the testing to achieve a maximum bi-directional loading of 34 MN, resulting in a top down equivalent loading in excess of 64 MN, allowing for buoyant weight above the O-cell level.



Figure 8.- O-cell bearing plates in position in the barrette cage.

### **Rectangular Barrette 7 metres long**

The loading assembly for the rectangular 1.2 m x 7 metre long barrette contained four 610 mm diameter O-cells, to spread the load evenly throughout the cross section of the barrette, shown in Figure 9 mounted between the bearing

plates. The O-cell arrangement was placed 2.3 metres above the base of the excavation at a depth of 50 m and constructed under bentonite slurry. Concrete was delivered by three tremie pipes to allow fast and well distributed placement of the concrete. The barrette was then base grouted prior to testing.

A maximum bi-directional load of 54 MN in each direction was achieved with upward and downward movements of 7 mm and 43 mm respectively at a maximum applied end bearing pressure of 3,800 kPa.

At the maximum load the six LVWDTs (vibrating wire displacement transducers), used to monitor O-cell expansion, showed less than 5 mm difference across the plate indicating that little plate tilt or bending had occurred during testing.



Figure 9.- Bearing plates being assembled to carry the O-cells for the 7 m long barrette

### **Multi-Level Bi-Directional Testing**

#### **Dubai, Nahkeel Harbour Tower, UAE**

The Nahkeel Harbour Tower has been planned to be over 1000 m tall and is expected to take approximately 10 years to complete with 500,000 m<sup>3</sup> of concrete being required for its construction.

Sitting in the World's only inner city harbour at the heart of The Nakheel Harbour, a development precinct of 2.7 square kilometres, the 200 floor tower will be the largest of 40 towers planned for the development.

The project will be located at the intersection of Sheikh Zayed Road and the Arabian Canal, with Waterfront to the west and Deira to the east.

The footprint for such a landmark skyscraper, illustrated in Figure 10, necessitates very high foundation loadings. The design called for 400 barrettes to be used on this project. To provide detailed geotechnical information and test barrette performance, three tests were requested by

consultants Golders to provide a geotechnical appraisal of the performance of the barrettes in the ground.



Figure 10 Artists impression

The tests were constructed in a multi-level O-cell configuration, using two levels of 2 x 870 mm O-cells in each of the 2800 mm x 1200 mm barrettes installed with base depths, two at approximately 65 m and one longer barrette at 95 m below ground elevation.

The positioning of the O-cell elevations was designed to check the performance of specific sections of the barrettes and to quantify the amount of end displacement under loading. Cyclic loading was also carried out. Placement of strain gauges along the cages provided detailed information of shaft friction mobilised.

The loading arrangement, with two O-cell levels set 17 m apart, provided the ability to achieve a gross O-cell loading capacity of 220 MN, a World Record for static load testing on a barrette (Figure 11 shows the test in progress at ground level).

The bi-directional technique allows such large loads to be applied even with a deep cut-off level. In this case the concrete was cast 19 m below ground elevation. Since the loading system is internal to the barrette structure, casting the concrete up to the design level removes the need for complicated methods to reduce or minimise the skin friction above. The purpose of the testing program was mainly geotechnical, this benefit, unique to bi-directional testing, proved to be invaluable.



Figure 11.- Multilevel bi-directional testing set up at the barrette head. The beam provides reference only as the loading is applied internally to the structure

Despite the huge loads applied to this test, the testing footprint, as for ANY bi-directional load test, is no bigger than the foundation element itself and can be tested without safety concerns associated with construction and performance of the loading system.

#### **Testing of Working Production Barrettes**

Post test grouting of piles tested with the O-cell method is common. Grout is injected through the hydraulic circuit and to the area around the O-cells to restore the structural integrity and compressive ability of the foundation element. Identical methodology has been applied to barrettes tested bi-directionally.

#### **Milan: Porta Nuova, Italy**

A prestige site in Central Milan required three working barrette tests to be performed. The redevelopment of the Porta Nuova Garibaldi district presented the perfect opportunity to prove the bi-directional technique on three working barrette tests to foundation contractor Fondamenta SpA., and although the loads required were not substantial (up to 25 MN mobilised load using pairs of 405mm and 510mm O-cells, as shown in Figure 12), testing by any other means would have proved difficult due to the poor soil conditions. Providing sufficient reaction loading from anchors would have presented many problems and it would not have been easy to construct a kentledge system that would have been stable on the soft ground.

As in many barrettes, cross hole sonic logging tests enable confirmation of the integrity of the shaft concrete. Provision for the placement of access tubes for the acoustic testing is made through cut-outs in the bearing plates. Since the logging is only required prior to the load testing, the tubes are designed to separate during

expansion of the O-cells. The tubes are filled during the post-test grouting process.



Figure 12.- The O-cell Assembly installed within the barrette reinforcement

With the bi-directional testing for barrettes, designers are just coming to terms with the implications for testing the full capabilities of their designs and using the system for testing their barrettes to their full capacities.

All three Milan test barrettes were subsequently grouted at O-cell level and incorporated into the working foundations.

#### **Las Vegas: Palazzo Condo Hotel - LBE-4, Nevada, USA**

For this project, artist impression shown in Figure 13, three barrettes, 860 mm x 3150 mm were tested on this site at varying lengths into clay, silty sands and intermittent very hard caliche deposits. The barrettes were constructed using a rectangular hydro-mill cutting system under bentonite slurry. This method allows the walls and the barrette base to be cleaned and well formed by circulating the chippings within the drilling slurry. The method is particularly well suited for excavating hard soils and rocks.



Figure 13.- Palazzo Condo Hotel Artists impression



Figure 14.- Cut-outs and funnel arrangements made to allow the use of two tremie pipes during concreting.

### **Singapore, Phoenix Hotel**

Refurbishment of the twin Orchard Road Shopping centres (Specialist Shopping Centre) in Singapore included rebuilding works on the Phoenix Hotel located between them. This prime location in the heart of Singapore will add more hotel rooms to a busy and thriving area.

In such a congested area, providing additional foundations in close proximity to an existing building required the use of barrettes as the preferred foundation element. One single level O-cell test a working barrette of 2800 mm x 1200 mm section was required to prove the design and load carrying capacity to 1.5 times working load. Twin 660 mm O-cells, shown in Figure 15, were installed in the weathered granite strata 1.7 m above the base of the 41 m long barrette to provide the required 37.8 MN test load. The working barrette was grouted after testing to allow the barrette to be incorporated within the foundation design.



Figure 15.- Installation of the twin 660mm O-cells within the working barrette.

### **General Observations:**

It is interesting to note that in certain circumstances, the O-cell level does not need to be precisely at a position where the capacity above and below the test barrette are identical. It is possible, with an assessment of the expected end bearing stiffness, to predict the mobilised load for a reasonable downward displacement which can be less than 50% of the ultimate end bearing capacity, described by England (2007). In so doing the full geotechnical capacity can still be deduced from the resulting behaviour under test.

The important aspect is that if sufficient of the skin friction and the end bearing can be mobilised to allow the geotechnical behaviour to be characterised, the total capacity of the barrette can be determined with O-cell expansion of no more than 150mm. In cases where the end bearing may be significantly larger than the skin friction, locating the O-cell assembly nominally at the base can achieve this outcome, however some care needs to be taken to ensure the end bearing behaves as expected. Some important recommendations follow:

1. Although it may be sometimes desirable to place the O-cell assembly immediately on the base of the barrette in order to have equal capacity above and below the O-cell to maximise the load which may be mobilised, it is sometimes difficult to ensure it engages directly with the soil below. To overcome this, the loading assembly can be placed slightly above the toe allowing space for concrete to be delivered below the assembly and to encourage the typical base cleaning effect the concrete flow may have.
2. Where the geometry of the barrette is large, it is advisable to consider using more than one tremie pipe for the concrete delivery, thus ensuring the cleaning effect described above is as well distributed along the base section as possible.
3. Where bentonite slurry is used, the build up of filter cake is to be avoided by minimising the standing time after completion of boring of the panel.
4. Cleaning of the base with methods such as airlifting is essential to remove any debris prior to concreting. Unlike bored piles, the excavation method of a barrette does not readily make cleaning of the base as straightforward. Grabs and similar techniques usually have large teeth which can lead to areas on the base that can trap sediment or debris, observation made by Berry (2009) who also describes methods of preventing such debris.

5. In addition to the above, it is recognised that the construction method can also leave an uneven base surface and it is advisable to consider some form of base grouting as a supplementary measure to ensure any debris caught at the base is suitably compressed before commencing the test.

### **Conclusions:**

It is possible to test barrettes to very high loading. The larger size of the barrette often enables a variety of loading configurations which are not restricted by the physical dimensions of the element as would be the case in a piled foundation.

The loading arrangement can be readily assembled using a selection of standard O-cell sizes available and several loading arrangements can be disposed at specific levels.

Bi-directional testing allows barrettes with low cut-off levels to be constructed early in the assessment phase without the need for mass excavation, de-watering or skin friction reduction methods.

The effect of shape factors on the design parameters of 'T' section barrettes can be measured directly.

Loading can be made directly within the desired strata at any location within the barrette shaft. Loading from the top of the barrette may require very high loads and internal stresses without actually mobilising the founding strata.

Bi-directional testing methods can enable the end bearing to be quantified by instrumentation or back analysis of load-settlement behaviour. Although the design of barrettes may often be done solely on shaft friction, the end bearing is commonly used as addition in the factor of safety. However, the end bearing is rarely mobilised sufficiently during traditional top-down testing to determine its true behaviour.

This testing method enables full scale testing of the foundation element and construction methods proposed for the working foundations, allowing the designer to quantify the soil parameters that will be expected using the techniques that will be employed during foundation production. Testing scaled pile tests is not necessary, avoiding the added uncertainty introduced with scaling up such tests where different construction methods have been used.

Post test grouting enables working barrettes to be incorporated in the foundation design after testing.

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