RECENT ADVANCE IN LOAD TESTING USING THE OSTERBERG LOAD CELL METHOD

by

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ABSTRACT

Ten years have passed since the first full-scale Osterberg Load Test was performed. Approximately 300 tests have been made in ten countries. Tests have been made on drilled shafts, barrette piles, driven pipe piles, and driven precast prestressed concrete piles to depths up to 90 m (300 ft.) and diameters up to 3 m (10 ft.). Test loads up to 133 MN (15,000 tons) have been applied. The loading device, called an O-cell, when placed on or near the bottom of the drilled shaft and pressurized internally, applies an equal upward and downward load, thus determining the side shear and end bearing separately. There is no need for a dead load nor hold down piles to react against as required in a conventional test. Experience has shown that the ultimate side shear for the great majority of tests is larger and sometimes much larger than that assumed by the designer. In the few cases where the side shear was low, it was often due to the method of drilling the hole. Insufficient cleaning and preparation of the bottom of the hole, indicated by large initial downward deflection of the bottom of the shaft, was apparent in many cases. Because the side shear was so much larger than that assumed, the working load when applied to the top of the pile would be mostly resisted by the side shear and little of the load would reach the bottom. The writer is disappointed that in many cases the design engineer was interested only in proving that the ultimate capacity exceeded the design load by a required factor of safety and was not interested in using the test results to design a more economical foundation.

INTRODUCTION

Drilled Shafts

The Osterberg Load Cell (also called O-cell) consists of a special designed hydraulic jack-like device capable of exerting very large loads at high internal pressures. Fig. 1 is a schematic diagram illustrating how the load cell works. A small amount of concrete is placed on the bottom of a drilled shaft after which the O-cell is lowered into the hole, which is then filled with concrete. A pipe welded to the top of the center of the cell extending to above the ground surface acts as a conduit for applying fluid pressure to the previously calibrated cell. Inside the pipe is a smaller pipe connected to the bottom with an open end. It extends to the surface and emerges from the large pipe through an O-ring seal. This pipe acts as a tell-tale to measure the downward movement of the bottom of the O-cell as load is applied. The fluid for applying the pressure can be oil or water. The liquid most often used is water with a small amount of miscible oil added to keep the pump equipment from rusting. After the concrete has reached its desired strength, the cell is pressurized internally creating an upward force on the bottom of the shaft and an equal but opposite force in end bearing. As the pressure increases, the telltale moves downward as the load in end bearing increases and the shaft moves upward as the side shear on the shaft is mobilized. It should be noted that at all times the total side shear resistance above the O-cell is equal to the end bearing resistance. Because of this, neither a reaction load nor a hold down pile frame system is needed as in the conventional test where the load is applied downward on the top of the shaft. The downward movement is measured by the dial gage 2, and the upward movement of the top of the concrete is measured by dial gage 1. Not shown on the figure is a pipe extending from the top of the load cell to above the surface in which is a telltale rod that measures the upward movement of the top of the cell. Thus, the difference between the measurement of this rod and dial gage 1 gives the compression of the concrete. From the data obtained as the load is increased, the load-upward movement curves and the load-downward movement curves can be plotted. After the test is completed, the O-cell chamber can be grouted if the shaft is to be used as a working shaft. About half the shafts tested have been working shafts.

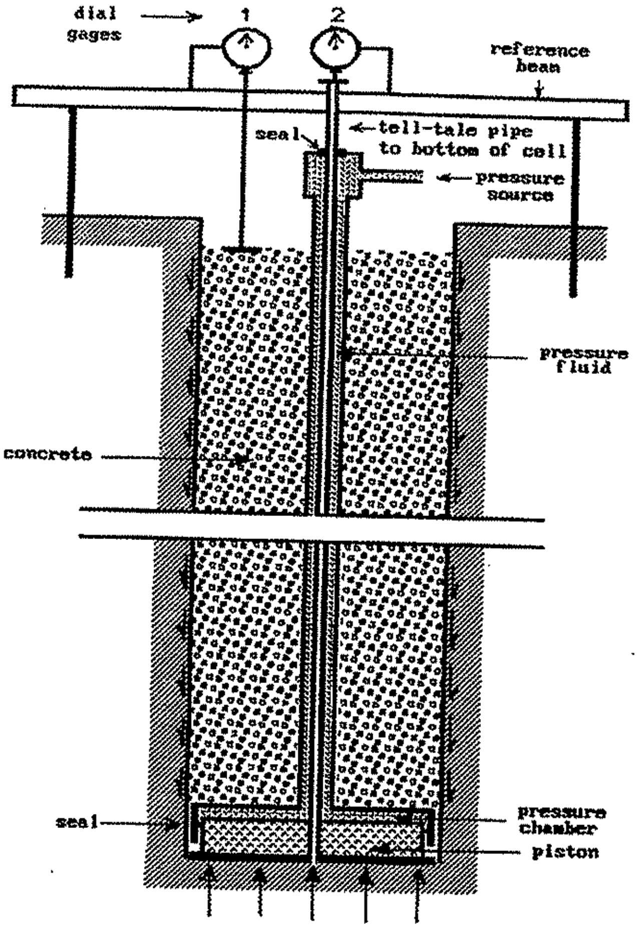


Figure 1 - Osterberg Cell Schematic

As the pressure increases, the ultimate value in either side shear or end bearing is reached or the load capacity of the O-cell is reached. Fig. 2 shows a typical set of load-deflection curves for a test. In this case ultimate was reached in side shear and the end bearing did not reach its ultimate value. It should be noted that the ultimate in side shear is usually reached at small movements, about 5-10 mm (1/4 -1/2 inch) for clays and somewhat larger movements for sand. Fig. 3 shows a typical case where the ultimate is reached in end bearing. Notice that even though the downward movement has reached 2.2 inches (56 mm) the upward movement is only 0.1 inch (2.5mm).

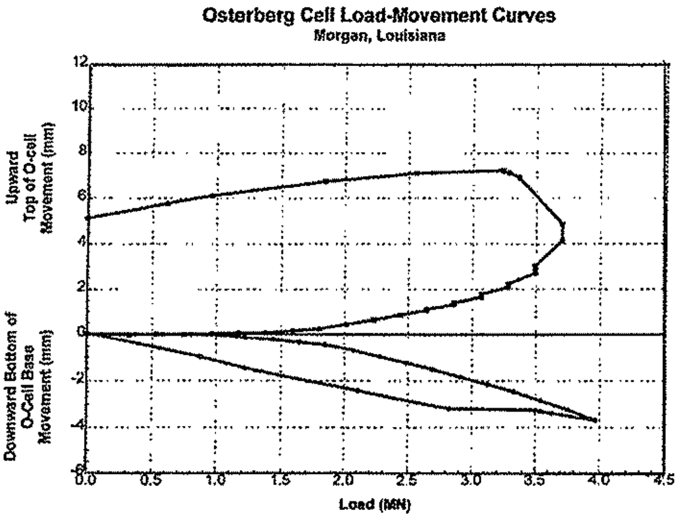


Figure 2 -Load Deflection Curves (Ultimate Side Shear is Reached)

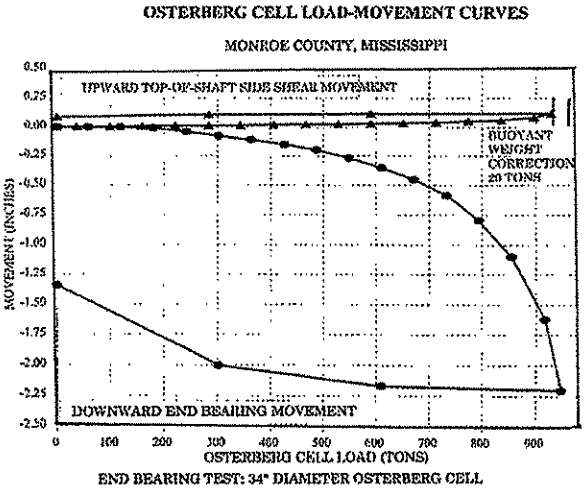


Figure 3 - Load Deflection Curves (Ultimate End Bearing is Reached)

As the drilled shafts tested became larger and larger in diameter and more of the shafts had reinforcement cages extending to the bottom, the center pipe was in the way during installation and it was found much easier to use the arrangement shown in Fig. 4. However, the arrangement shown in Fig. 1 is still used for small diameter shafts and for some of the driven piles. In Fig. 4, it is seen that the hydraulic supply lines (consisting of high pressure hoses) and the telltale rods are at two locations 180 degrees apart. Also, the opening of the cell as pressure is applied is measured by vibrating wire displacement transducers. The dial indicator readings, pressure transducer readings and any strain gage readings are all recorded on a data logger.

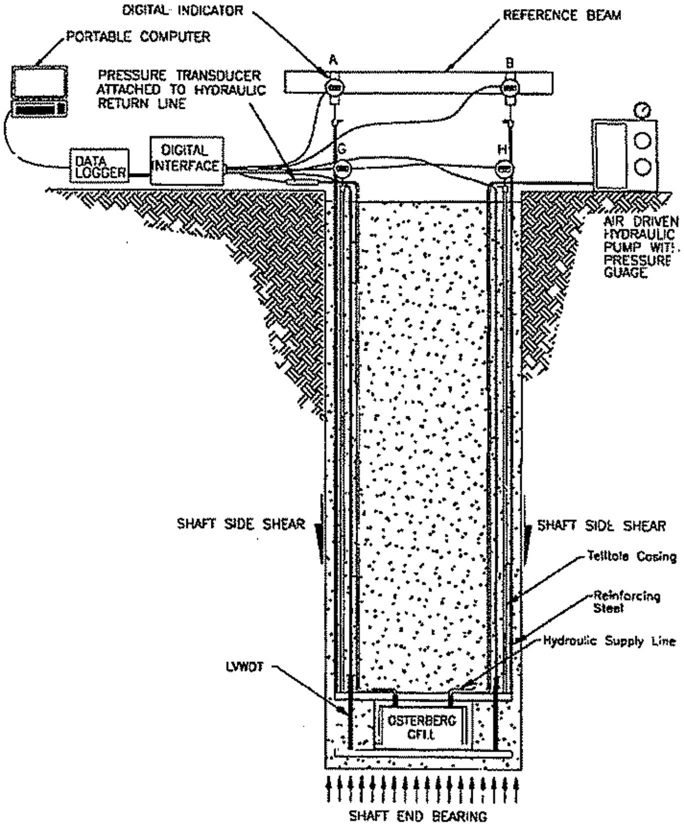


Figure 4 - Modified O-cell Arrangement

Loads can be applied at any rate, can be held at a given magnitude for any time interval required, and the drilled shaft retested after weeks, months or even years. The most common and most appropriate loading sequence

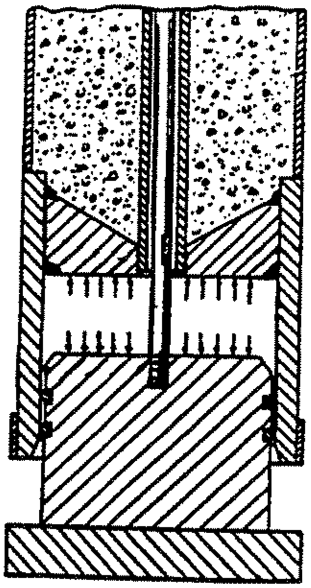


Figure 5 - O-cell Driven and Partially Extended

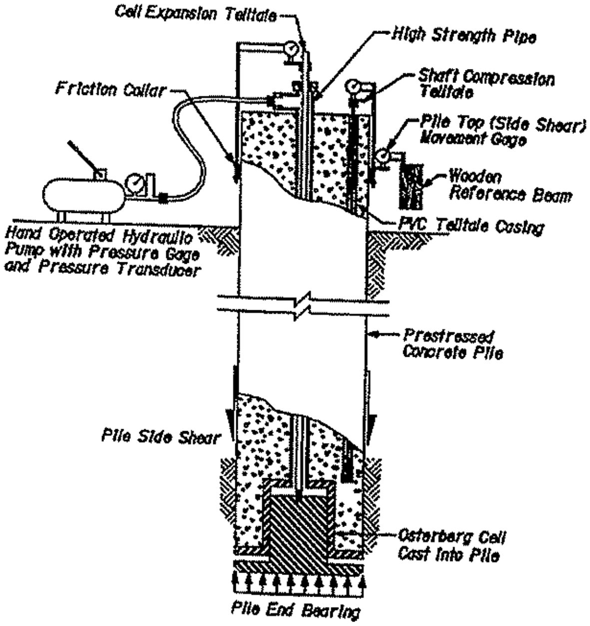


Figure 6 - Typical O-cell Installation, Cast in Concrete, Ready for Testing

used is the ASTM Quick Test Method D1143 (ASTM 1993) The O-cells range in capacity from 670 kN (75 tons) to 27 MN (3000 tons) (in each direction) and in diameter from 133 mm (5 ¼ inches) to 865 mm (34 inches). The total stroke is 150 mm (6 inches). However, in Japan where many cycles of loadings are used, the total stroke is 150 mm (12 inches). Where test loads larger than 27 MN (3000 tons) in each direction are required, two or more O-cells are used. For example in the largest test made to date of 133 MN (15,000 tons - 7,500 up and 7,500 down), three cells placed between two rigid plates were used.

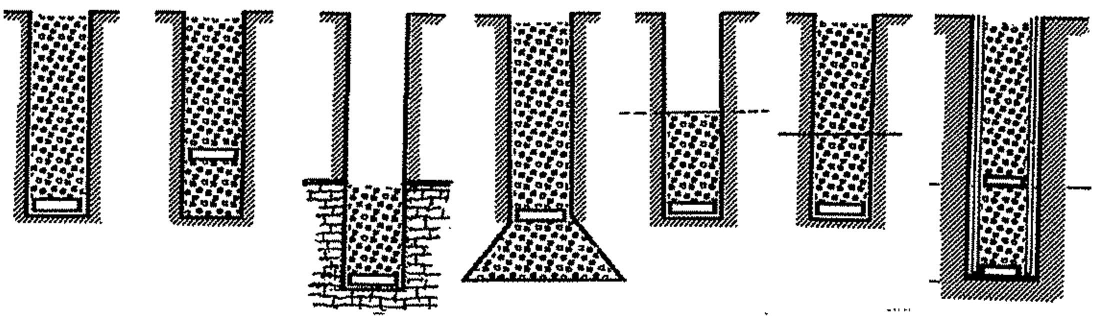
Driven Piles

Tests have been made on pipe piles and pre-cast concrete piles. For pipe piles the O-cells are welded directly to the bottom of the pipe and driven with the pipe as illustrated in Fig.5.

Fig. 6 shows a cell cast into a concrete pile and in place ready for testing. This pile has a square cross-section 460x460 mm (18x18inches). The pile was designed for installation at 5 different locations with 5 different soil conditions to determined the increase in side shear over a 2 year period. The hand pump, dials and auxiliary equipment were moved from site to site as testing at increasing time intervals proceeded. Similar tests have been made on larger pre-cast square concrete piles.

Applications

Tests have been made on drilled shafts with the O-cell placed in various locations in the drilled shaft as shown in Fig. 7.



7a 7b 7c 7d 7e 7f 7g

Figure 7 - Alternative Positions for Placement of O-cells

Fig. 7a. Shows the most commonly used installation where the cell is at the bottom of the hole after a small amount of concrete is placed to seat the cell. This is appropriate where the estimated side shear resistance is approximately equal to the end bearing or where the end bearing is large in comparison with the side shear and only the total ultimate side shear is to be determined. and the side shear is determined to be greater than the end bearing)

Fig. 7b. If it is desired to determine the combined ultimate capacity of the shaft, the cell is placed at a predetermined distance above the bottom. If the distance is determined correctly, then the ultimate side shear above the cell will be reached when the side shear plus the end bearing reaches its ultimate value. Though it is not possible to predetermine the exact location of the cell, experience has shown that when the upward load or downward load reaches its ultimate, often the other load is close to its ultimate.

Fig. 7c Shown is the method of determining the side shear and end bearing in a rock socket independent of the side shear of the overburden. If the additional ultimate side shear of the overburden is desired, then after testing the rock socket, the remainder of the shaft can be filled with concrete and after reaching sufficient strength, the drilled shaft can be tested again.

Fig. 7d In cases where the estimated end bearing is less than the side shear, and the ultimate side shear is to be determined, then a bell can be excavated below the bottom and the cell place on top of the bell.

Fig. 7e There are cases where the top of the shaft is some distance below the ground surface and after installation and testing, excavation will be made for a basement. Then the pressure pipes and telltales can extend up from the top of the shaft to the existing ground surface.

Fig. 7f Where the ultimate side shear of two layers are to be determined, the concrete can be filled only up to the top of the lower layer and tested. After filling the rest of the shaft with concrete, it can be tested again to obtain the combined ultimate side shear of the entire shaft..

Fig. 7g By using two cells with one at the bottom and the other at a predetermined distance up from the bottom, the ultimate side shear of the shaft above the upper cell, the side shear of the shaft below the upper cell and the ultimate end bearing can frequently all be determined. To accomplish this, the o-cell loads are applied in stages.

TOP DOWN EQUIVALENT CURVE

A curve equivalent to applying the load at the top of a shaft can be constructed from the upward movement-side shear curve and the downward movement-end bearing curve. This is done by determining the side shear at an arbitrary movement point on the side shear curve. If the shaft is assumed rigid, the top and bottom move the same amount and have the same movement but different loads. By adding the side shear to the end bearing at the same movement, a single point on the top down equivalent curve is obtained. By repeating this process for different deflection points, the top down equivalent curve is obtained.

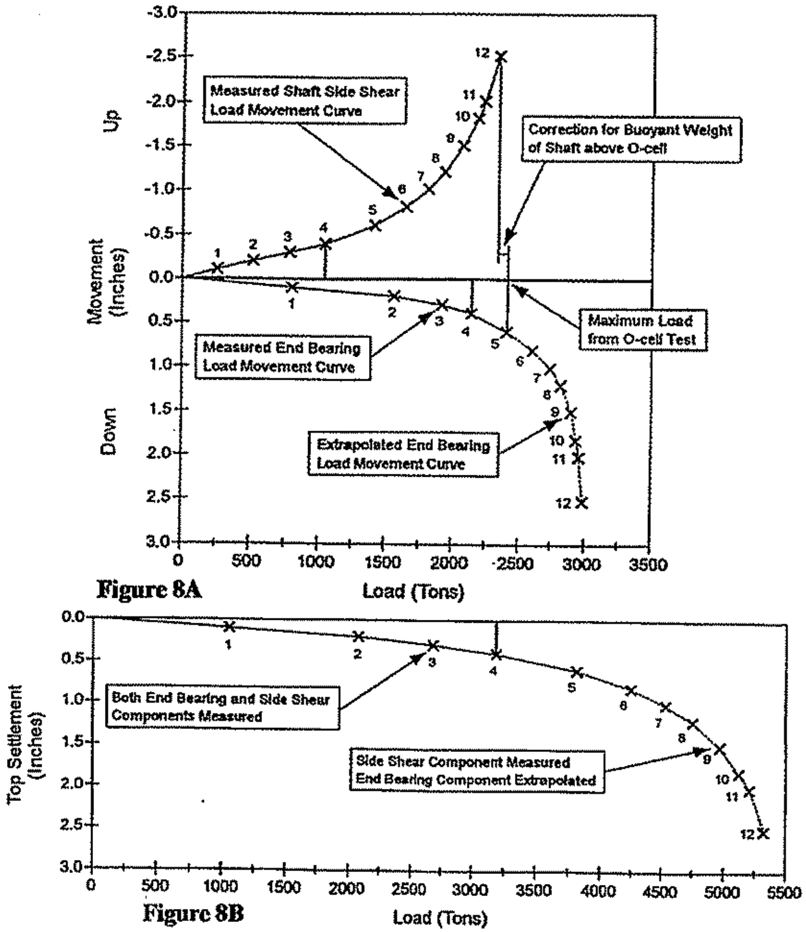


Figure 8A

Figure 8B

Example of the Construction of a Equivalent Top-Loaded Settlement Curve (Figure 8B) from O-Cell Test Results (Figure 8A)

Figures 8A and 8B detail the process. Pick an arbitrary point such as 4 on the measured side shear curve (Fig. 8A). Find the point 4 on the measured end bearing curve which has the same deflection. Since the shaft is assumed incompressible, the top of the shaft moves down the same as the bottom in a top down curve. Since the deflections at both points 4 are the same, the load for a top down test having the same deflection is the sum of the side shear(1040 tons) and end bearing at point 4 (2140 tons) which is shown at point 4 in Fig. 8B (3180 tons). By repeating the process shown by points 1-5, the equivalent top down curve equivalent to the measured side shear and measured end bearing curves is determined as shown (Fig. 8B). It so happens that point 5 is the last point on the end bearing curve. To extend the top down curve beyond points on the end bearing curve, it is extrapolated to the same maximum deflection of the side shear curve (point 12). By using a hyperbolic extrapolation, points 6-12 on the end bearing curve are obtained. The process is then continued to obtained points 5-12 on the equivalent top down curve, which is the portion of the equivalent curve for which the side shear component was measured and the end bearing component was extrapolated. The same procedure can be used if the ultimate side shear is greater than the end bearing. When one component reaches ultimate before the other, two procedures are possible. One procedure, which is extremely conservative, is to assume that the other component has also reached ultimate and that no further load increase occurs as deflection increases. The other more likely procedure is to extrapolate the curve which has not reached ultimate as shown here. The equivalent top down load-deflection curves for a few O-cell tests are shown in Figs. 18, 20. & 22.

The reconstructed top down curve is made on the basis of three assumptions:

1. The side shear-deflection curve for upward movement of the shaft is the same as the downward side shear-deflection component of a conventional top down test.
2. The end bearing load-deflection curve obtained from an O-cell test is the same as the end bearing-load deflection component curve of a conventional top down test.
3. The shaft is considered rigid. For concrete shafts the compression of the shaft is typically 1-3 mm.(0.04-0.12 inches) at ultimate load.

Test data discussed in the following section indicates that these assumptions, though not exactly correct, do give close agreement between the constructed top down test and actual conventional top down tests.

TESTS TO DETERMINE VALIDITY OF OSTERBERG CELL METHOD

Comparisons from Strain Gage Readings

In many of the tests made, strain gages have been installed at various levels in the shaft. One such installation is illustrated in Fig. 9. Strain gages were installed above the O-cell at the levels shown. Each of the strain gage readings was multiplied by the Young's modulus of the concrete and the cross-sectional area to determine the load transmitted in the shaft. The distribution of the these forces was determined for

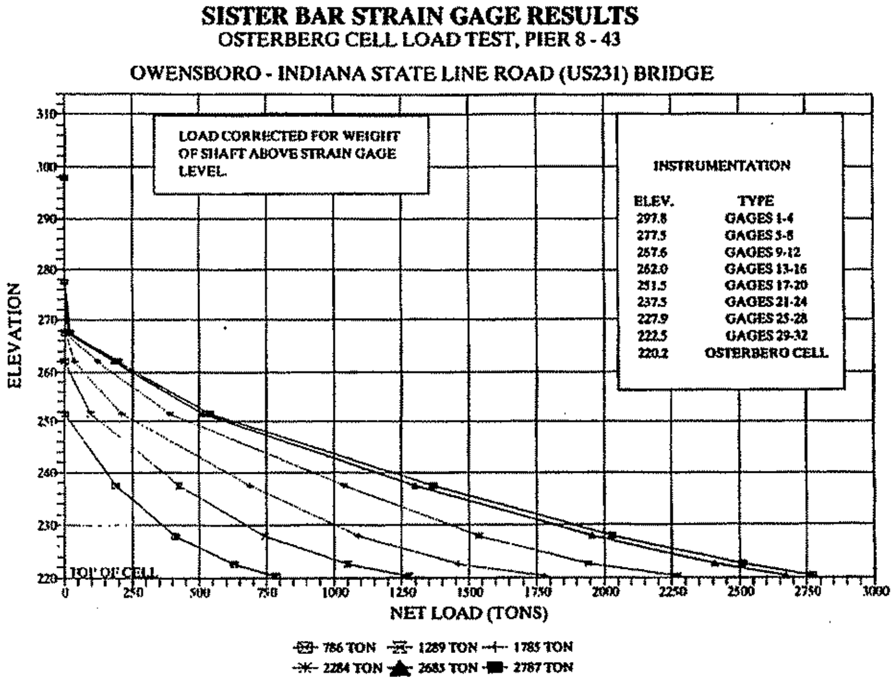


Figure 9 - Comparisons from Strain Gage Readings

five different forces exerted by the O-cell. It is seen that the force applied by the load cell is on the line of force distribution with depth for each of the applied loads. This and many other examples indicate that the actual force applied by the cell installed at the bottom of the shaft as determined from its prior calibration agrees with the force as measured by means of the strain gages.

Comparisons with Full Scale Load Tests made in Japan

Many tests have been made in Japan to confirm the validity of the O-cell tests (1)(2). One series of tests were made on drilled shafts and another series on driven piles. For the drilled shaft series six tests were made at different sites.

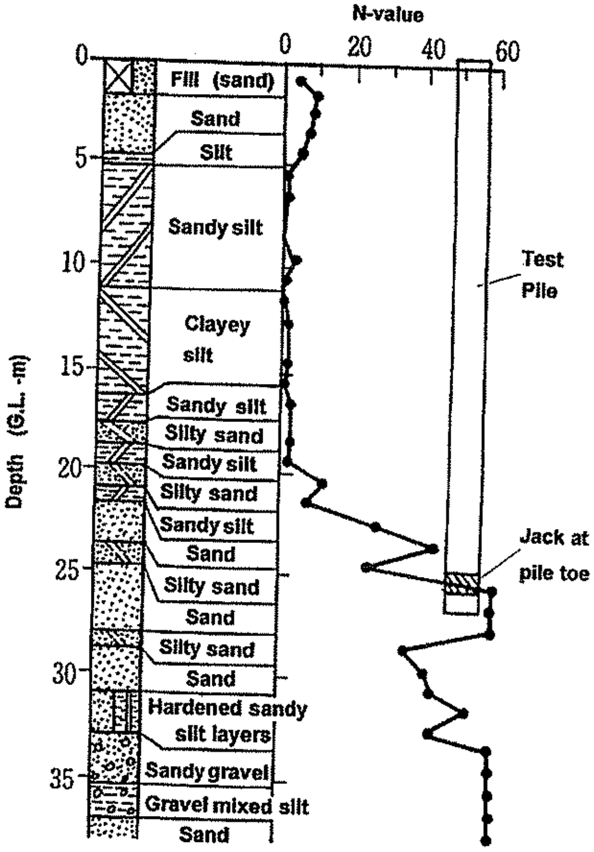


Figure 10- Soil Profile for Comparison Tests

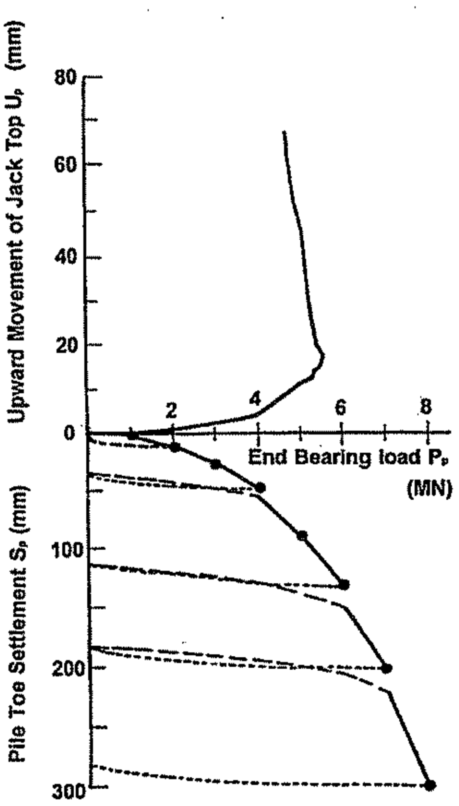


Figure 11- Determining end bearing with O-cell independent of side shear

Fig. 10 shows the soil profile at one of these sites. The shaft was 1.2 m (4 ft) in diameter and 26.5 m (87 ft) in length. The hole was bored using drilling mud and the concrete was placed under drilling mud with a tremie. The results of the test are shown on Fig. 11. The tests were carried out with four cycles of load as is the usual practice in Japan. In this test it was predetermined that the side shear would be less than the end bearing. In order to obtain the ultimate load in end bearing, a load frame was used over the pile to hold down the pile for the additional load needed after the ultimate side shear was reached. A load cell was installed at the top of the shaft. When the ultimate side shear was reached, indicated by continuous upward movement of the shaft without any increase in load, the load frame was placed over the shaft. Fig. 12

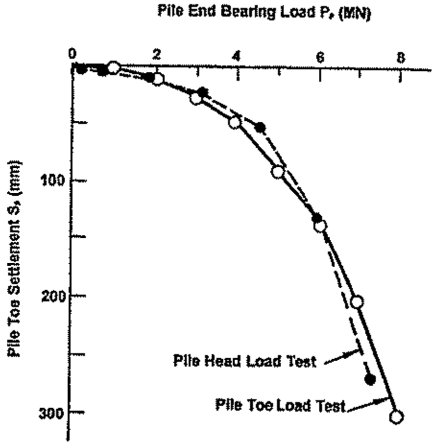


Figure 12

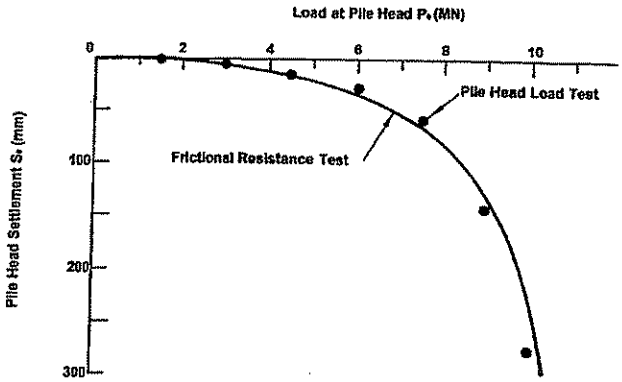


Figure 13

shows the comparison of the deflection-end bearing curve obtained from the O-cell test with that obtained from the top down test. Fig. 13 shows the comparison between the top down test and the top down load test as calculated by load transfer analysis using the side shear resistance obtained by O-cell readings. The close agreement of these curves is another indication of the validity of the Osterberg Load Test. In the other series of tests on driven piles, seven tests were made, three in clay and four in sand. The soil profile for one of these test locations is shown in Fig. 14. The pile was 0.5 m (1.6 ft.) in diameter and 9 m (30 ft,) long. Fig. 15 shows the results of a test in which the O-cell was on the bottom and a calibrated jack on the top of the pile. The pile was held fixed and the O-cell pressurized to determine the end bearing independent of the side shear. The end bearing as measured from the top and that as measured from the O-cell are compared in Fig. 15. In another test at the same site, the pile was first tested by pushing up from the bottom with the O-cell and pushing down from the top with the O-cell de-pressurized so that there is no end bearing.

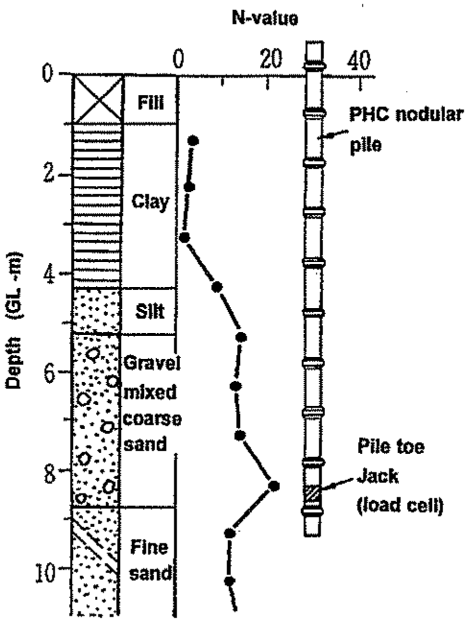


Figure 14 - Soil Profile for Driven Piles

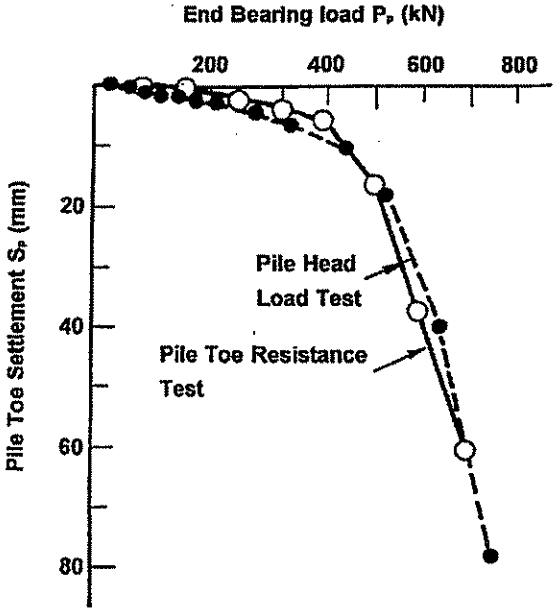


Figure 15 - Comparison Test Results

Fig. 16 shows the comparison between the side shear measured pushing up with the side shear measured pushing down. These tests results are further evidence of the validity of the O-cell test being essentially the same as a conventional top down test.

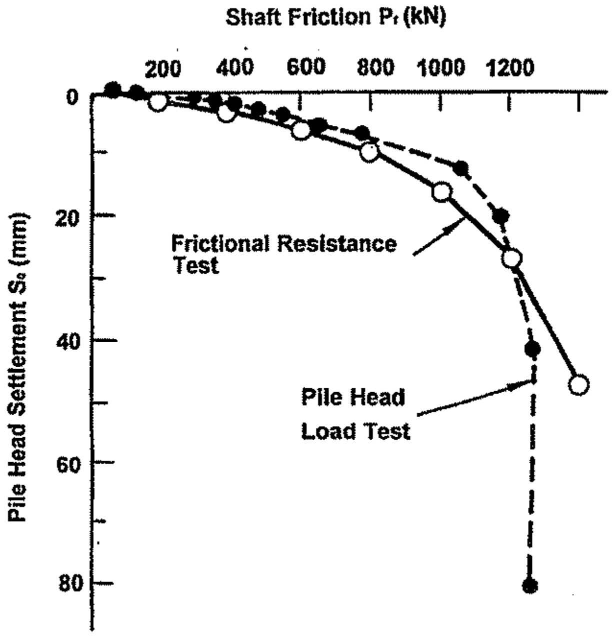


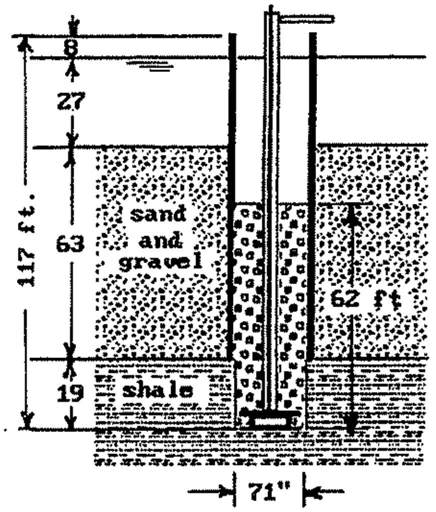
Figure 16 - Comparison of Side Shear Values

CASE HISTORIES

Some typical and atypical examples are given below. New successive world records for test loads were made in recent years:

Location	Shaft Diameter	Depth	Maximum Load
1. Ohio River Bridge,Kentucky	1.8 m (6 ft.)	36 m (117 ft.) from water level	54 MN (6,200 t.)
2 St. Mary's River,Georgia	1.5 m (5 ft.)	23 m (75 ft.)	65 MN (7,300 t.)
3. Penang, Malaysia	6 x 1 meters (barrette)	91 m (300 ft.)	97 MN (11,000 t.)
4. Apalachicola River, Florida	2.75 m (9 ft.)	39 m (127 ft.)	133 MN (15,000 t.)

Ohio River Bridge - Owensboro, Kentucky



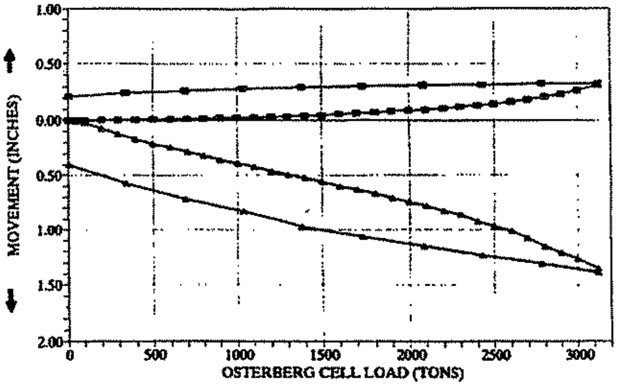


Figure 17- Ohio River Bridge Test

This test was in 8 m (27 ft.) of moving water. Because of possible deep scour in the future, only the load capacity of the 6 m (19 ft.) of shale was to be considered in the design. The rock consisted basically of shale with layers of coal and sandstone seams, which would be difficult to assess without actual full size testing. As shown in Fig. 17, concrete was placed some distance above the top of the shale. However, the strain gage readings in the concrete above the shale indicated that the load taken above the top of the shale was negligible compared to the load taken by the shale socket. Since the test was designed to reach three times the design load and the ultimate capacity was much larger than anticipated, the test load could only be taken to the maximum load capacity of the O-cell. The hole was drilled with polymer slurry.

Bridge Foundation - East Milton, Massachusetts

The soil profile consists of overburden underlain by shale. The purpose of the test was to determine the side shear and end bearing of the rock socket. The O-cell was placed at the bottom of the socket. It is seen from Figure 18A that by chance the ultimate shear and ultimate end bearing occurred at virtually the same deflection, 27.6 MN at 15 mm and 28 MN at 19 mm (3,120 tons at 0.60 inches and 3,160 tons at 0..75 inches). Since this was a test shaft, the values of side friction and end bearing were used to design shorter shafts than planned. Fig. 18B shows the equivalent top down curve with an ultimate capacity of 56 MN (6,300 tons). This also was the rated maximum capacity of the cell. The fact that the ultimate capacity in shear and end bearing was reached at almost the same load and deflection and at the maximum designed capacity of the O-cell is a circumstance which will rarely occur.

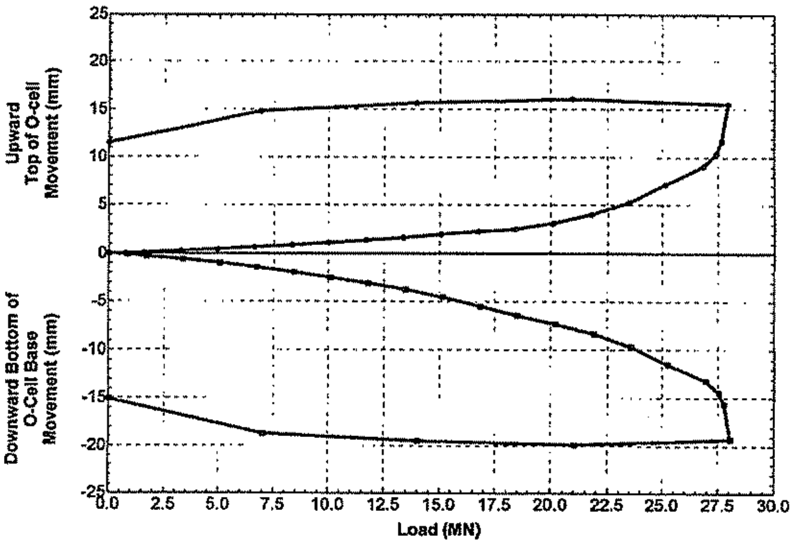


Figure 18A - O-cell Load Movement Curves

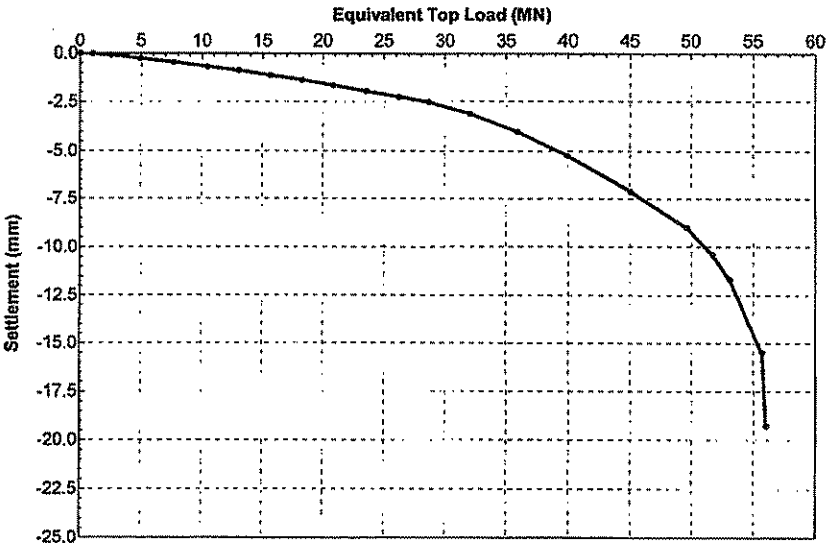


Figure 18B - Equivalent Top-Load Settlement Curve

Barrette Test - Alfaro Peak, Manila, Philippines

The barrette was 0.8x2.8 m (2.8x9 ft.). The soil profile consists of 12 m (40 ft.) of silty clay under which is 2.5 m (8 ft.) of silty sand. Below this are siltstones and sandstones with the bottom of the barrette at a depth of 28 m (92 ft.) and socketed in 13 m (43 ft.) of weak siltstone and sandstone. Fig. 19 shows the test setup. It is seen that the test is to be made from the present ground surface and that 12 m will be later excavated for the basement. Two O-cells were placed at the bottom of the reinforcement cage. Telltales are placed in the top of the permanent concrete at the cut-off level so that the compression of the barrette can be determined. Fig. 20A shows the load-deflection curves carried through two cycles of loading and that the ultimate load in side shear for the second cycle occurs at about the same load as the first cycle (which is almost always observed when two or more cycles of loading are applied). However, in end bearing, the second cycle of loading resulted in 8 mm (0.30 inches) of settlement whereas the first cycle caused 55 mm (2.1 inches) settlement. Most of the settlement in the first cycle is due to disturbance below the bottom of the barrette. The remarkable decrease in settlement for the second cycle indicates that the O-cell precompresses the bottom and reduces the top-down settlement shown in Fig. 20B where the lower curve shows the top down equivalent curve for the first cycle and the top curve for the second cycle of load. The results show that better cleaning of the bottom of the hole can give substantial load capacity to subsequent barrettes at the site.

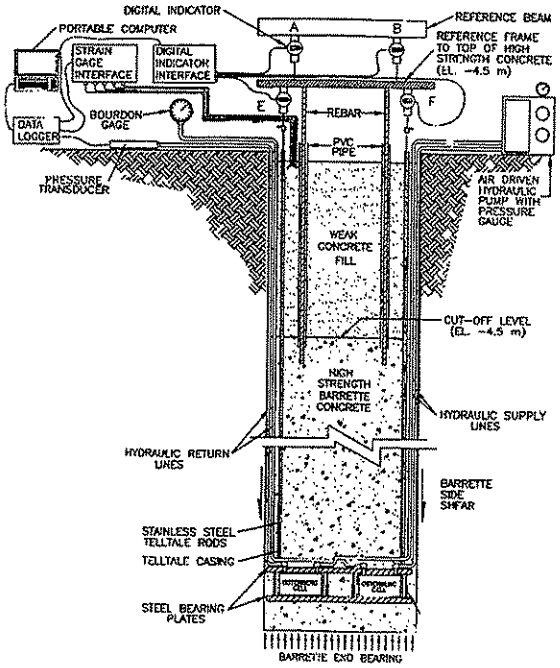


Figure 19 - O-cell Setup - Alfaro Peak

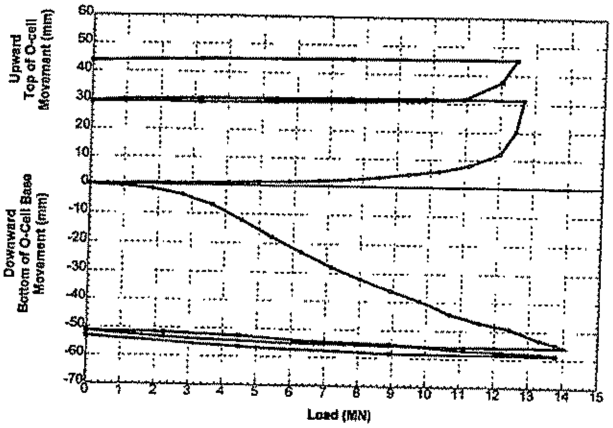


Figure 20A - O-cell Load Movement Curves, (Alfaro Peak - Manila, Philippines)

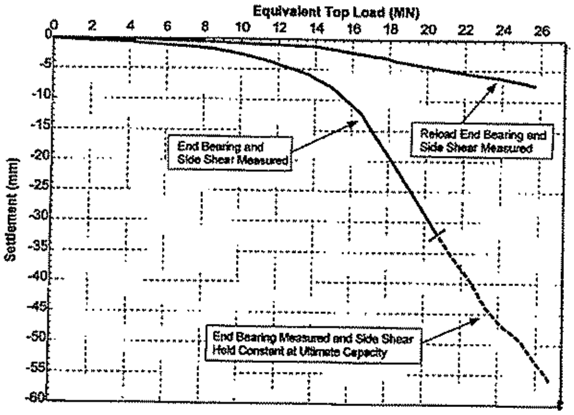


Figure 20B - Equivalent Top-Load Settlement Curve (Alfaro Peak - Manila, Philippines)

World Record Test - Apalachicola River, Florida

The test was made on a working shaft using three O-cells installed at the same level and installed 2.1m (7 ft.) from the bottom of a 2.7 m (9.0 ft.) diameter socket 23.7 m (50 ft.) deep. The total shaft length was 31 m (102 ft.) below river bottom. The water was 6.1 m (20 ft.) deep. The distance from the bottom was estimated to be at the level where the upward ultimate resistance would be approximately equal to the downward resistance (i.e. end bearing plus the side shear of the shaft below the O-cells). Fig. 21, showing the two load-deflection curves indicates that ultimate shear was reached at 65 MN (7,400 tons), not very much less than the maximum capacity of the three cells. The ultimate end bearing was not reached but it was estimated by extrapolation to be between 8,000 and 9,000 tons (70 and 80 MN). The total tested capacity was 133 MN (15,000 tons).

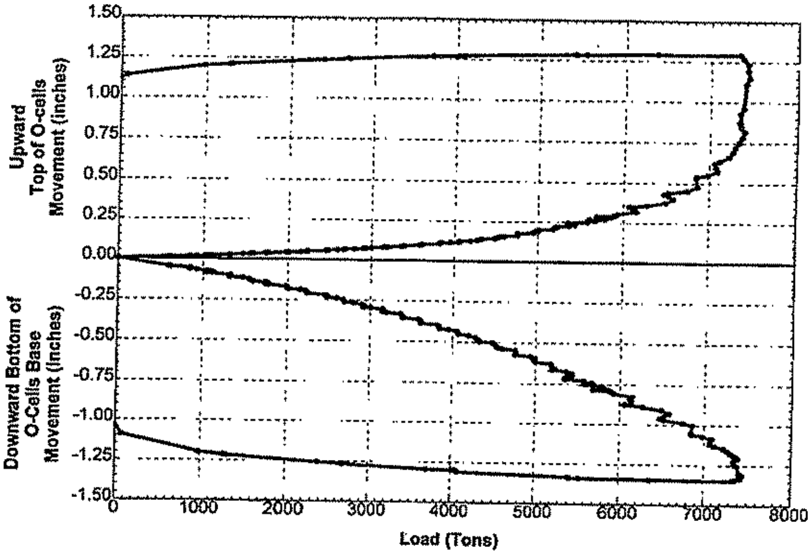


Figure 21 - Load Deflection Curves, Apalachicola River, FL

WHAT HAS BEEN LEARNED FROM THE OSTERBERG LOAD TESTS

General

When there have been no deficiencies in the process of drilling the shafts, it has been found in the vast majority of tests, that the maximum test loads achieved with the O-cell is much larger than the design load including the factor of safety. In only a relatively few cases did the designer take advantage of the results to redesign the shaft to achieve a more economical foundation. In many of these cases, it was considered to be too late in the construction process to make any foundation design changes. In other cases, the engineer was only interested in proving that the design was safe no matter how large the factory of safety was found to be. An extreme example of over design is shown in Fig. 22A. The design load was 500 tons (4,400 kN). The test was carried to over 3,000 tons (26.5 MN) with no

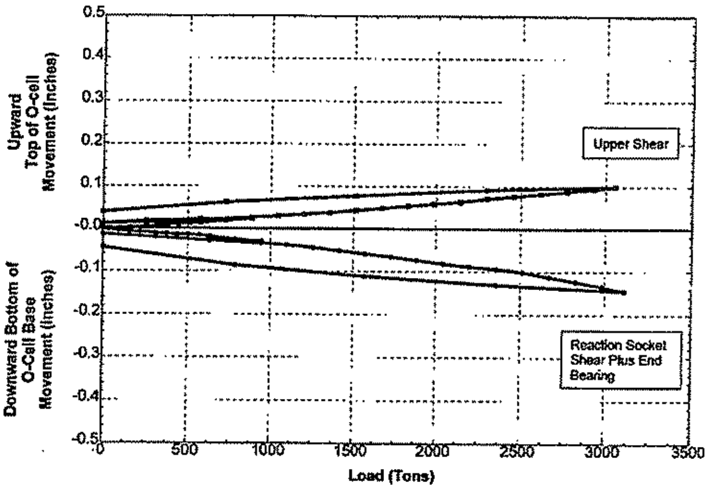


Figure 22A - O-Cell Load-Movement Curves sign of approaching failure in either side shear or end bearing. The equivalent top down load-settlement curve shown in Fig. 22B reached 5,600 tons (50 MN) with a total settlement of 0.1 inch (2.5mm)! Thus, at 11 times the design load there was virtually no settlement! The owner's engineer was very pleased that his design was safe, but no efforts were made to change to a more economical design.

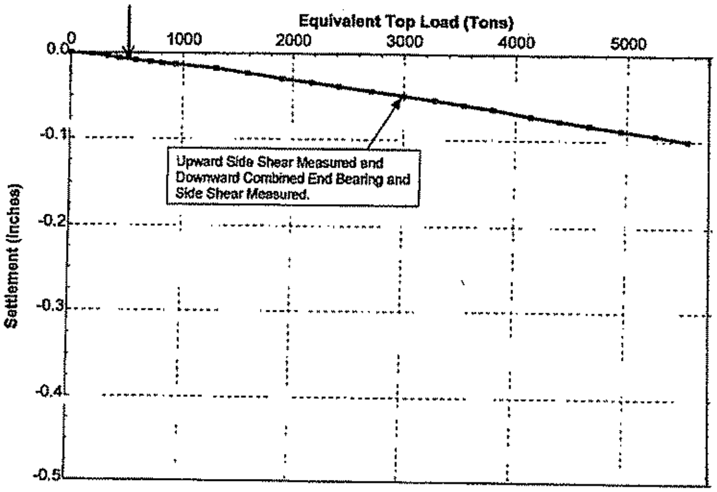


Figure 22B - Equivalent Top-Load Settlement Curve)

It is understandable that, in many instances when the O-cell test is made on a working shaft, the possible delay due to redesign and re negotiation with the contractor is not worth the possible savings. However, when the possible savings and time delay are not even estimated, this is not excusable. On large projects, it would be far better if a test shaft (which may later become a working shaft) is installed before the contract is let and the results used to make a more rational and economical design than to make the test on a working shaft when construction has already begun. There have been cases in which twice the design load was reached with very little upward or downward movement, and it was ordered to go no further with the test even though the load could be increased to either the ultimate load or the capacity of the O-cell which ever occurred first. It would take very little extra time and there would be no increase in the cost of the test.

Observations Relative to Side Shear

The ultimate side shear determined in the O-cell test has almost always resulted in much larger values than estimated by the designer. In the few cases where the ultimate side shear was about what the designer estimated or less, it was found to have been due to the way the shaft hole was drilled. In one case where a shaft was drilled in a lava rock, the ultimate side shear was found to be much less than one would expect. It was learned that the particular machine which drilled the hole used a drilling tool with oscillating circular motion which polished the side wall of the rock. It was found in a subsequent test using the same machine in the same type of rock at a nearby location that by slightly roughening the side wall after drilling by simply whipping a frayed cable around the hole, that the ultimate side shear was much larger.

In drilling in cohesionless or slightly cohesive soils using mineral slurry or without a slurry where there is some seepage into the hole, it is sometimes found that the ultimate side shear is less than is normally expected. It was found not to be due to the slurry per se, but due to the procedure in processing and using the slurry. See Schmertmann and Hayes (3).

Observations Relative to End Bearing

Since with the O-cell, the end bearing-deflection curve is determined independently from the side shear-upward deflection curve, shaft bottoms which have not been adequately cleaned of disturbed material can easily be determined from the shape of the curve. This is illustrated in Fig. 23 where it is seen that about 100 mm (4.9 inches) of downward movement occurred in end bearing . At the ultimate shear resistance, the upward plus downward movement was 160 mm (6.3 inches), which came very close to pushing the piston out of the cylinder, causing a leak and loss of pressure. Since the stroke with the standard O-cell design is 150 mm (6 inches), considerable downward movement can occur to fully compress the disturbed material and transfer the load to the undisturbed material below. A common observation for shafts ending in sand, is that a second cycle of downward loading will yield a much smaller deflection, indicating that the first cycle precompresses the sand for subsequent loads including the design load (see Fig. 20A and 20B).

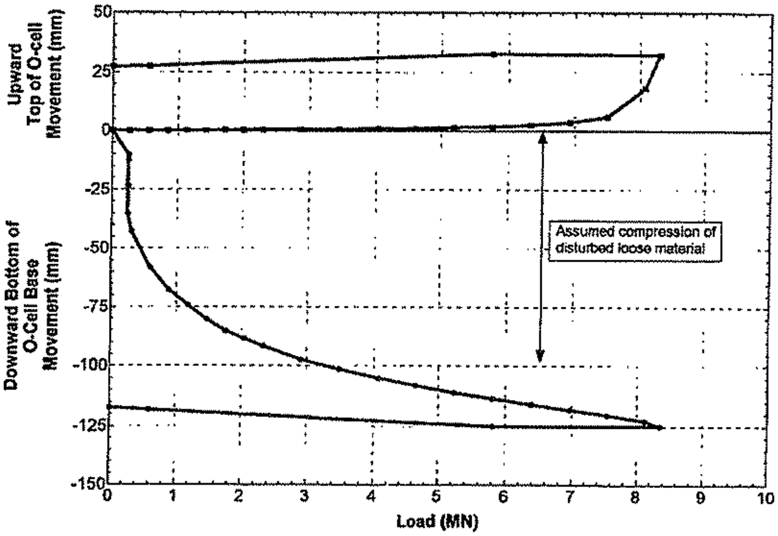
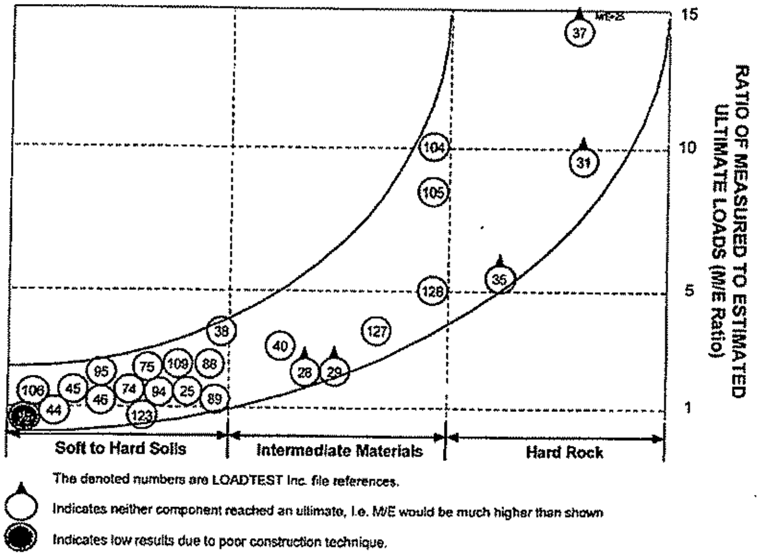


Figure 23 - O-cell Load-Movement Curves

It should be noted that in a conventional top-down test loaded to two times the design load, the side shear takes most of the load with very little of the load reaching the bottom and thus disturbed material on the bottom is not detected. Using the O-cell, bottom disturbance can be detected and action taken to more adequately clean the bottoms of subsequent holes and thus increase the load capacity of the shafts.

Observations from O-cell Test Results

As stated previously, in the large majority of the shafts tested, it was found that the measured shaft capacity was considerably greater than the estimated capacity. It has been shown (Schmertmann and Hayes (4)) that the amount by which the excess capacity exceeds the estimated capacity increases as the strength of the supporting material increases. 25 tests in which there was enough information regarding the strength of the supporting medium were studied and



The denoted numbers are LOADTEST Inc. file references.

Indicates neither component reached an ultimate, i.e. M/E would be much higher than shown

Indicates low results due to poor construction technique.

Figure 24 - Ratio of Measured to Estimated Ultimate Loads (M/E Ratios)

compared to the engineer's estimated capacity. It was found that the ratio of the measured to estimated capacity (M/E) tends to increase as the strength of the supporting medium increases, as shown in Fig.24. It is seen that for soft to hard soils, the M/E ratio varies from about 0.7 to 3. For intermediate soils such as coarse sands, dense silts, glacial tills and weathered rock, the ratio increases to about 3 to 5. For hard rock, the ratio is from 5 to above 15! Thus, somewhat ironically, the harder the medium the shaft is in the more the load capacity of the shaft is underestimated

Code Requirements

Codes and governmental rules concerning drilled shafts vary widely among countries and even among the 50 United States. In one Asian country, the code requires a drilled shaft to be designed in side shear and does not allow any end bearing if the shaft is constructed using drilling mud. In another Asian country, the code specifies that drilled shafts be designed using only end bearing with no side shear. One highway department in the U.S.A has found that the bottom of drilled shafts are disturbed and does not allow any end bearing to be used in design. Certainly all the 300 tests made with the O-cell have shown that no matter how small, there is always some side shear and some end bearing. Where either side shear or end bearing has been found to be lower than one would expect, it has always been shown to be due to improper construction techniques. In the Boston area, because piles are driven through a soft blue clay to a very hard, high load bearing glacial till, no side shear is commonly used. Yet a 20-inch (500 mm) pipe pile with an O-cell on the bottom and driven through 100 ft. (30 m) of the soft clay to the glacial till and tested, indicated that the driven pile had an ultimate side shear of 140 tons (1,200 kN).

SUMMARY AND CONCLUSIONS

1. Total test loads (up+down) have increased from less than 9MN (1,000 tons) to 135 MN (15,000) tons.
2. Engineers tend to seriously underpredict the capacity of bored piles when properly constructed. The underprediction tends to increase the stronger the soil and/or rock. The underprediction is the greatest for rock sockets.
3. Many engineers do not take advantage of the O-cell test results to design more economical bored piles.
4. The O-cell test method has proven to be very versatile for use in situations where the conventional top-down method is impractical, i.e. over water, in crowded and inaccessible places, testing rock sockets, and where the test loads are very large.
5. Data have been accumulated to support the validity of the O-cell test method's ability to adequately duplicate the results from conventional top-down testing.
6. The O-cell can detect defects in bored pile techniques which in most cases cannot be detected by the conventional top-down method.
7. In cases where the material below the bottom of the bored pile is disturbed, the end bearing capacity can be greatly increased by applying a preliminary load cycle.

8. The use of multilevel testing makes it possible to determine the side shear strength of different layers as well as the end bearing strength.

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