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The barge set-up for the Osterberg O-cell test at Incheon, Korea. The cable-stayed bridge over the Han River is in the background.

Reinforcing cage for the O-cell test site in Korea

The Landmark Osterberg Cell Test

In 1990, six years after creating it, Professor Jorj Osterberg despaired that his method for testing deep foundations might never be accepted by geotechnical engineers. On a sunny winter day in January of that year, however, five engineers (I among them) assembled at Dr. Osterberg's home in Aurora, Colo., to discuss the possibility of setting up a company to exploit what became known as the Osterberg Cell (O-cell) test. Little did any of us suspect that four eventful years later, the O-cell test would be nominated for ASCE's NOVA Award for significant contributions to the advancement of the construction industry, or that the Deep Foundations Institute (DFI) would select the Osterberg Cell test for the 2009 Ben C. Gerwick Award for Innovation in Design and Construction of Marine Foundations. And now, DFI has included the Osterberg Cell load test in this "Landmark" issue of *Deep Foundations* magazine. Sounds like a straightforward success story, but not so fast.

An initial test in 1984 using a rudimentary version of the O-cell in Case Foundations' backyard proved successful. At least the results looked promising in a shallow drilled shaft. In 1986, Dr. Osterberg received a patent for the process.

The first commercial application took place in 1987 at the Saugus River railway bridge site in Massachusetts on a driven pipe pile. This test was a success thanks to the effort of Charlie Guild, the former (now deceased) president of American Equipment and Fabricating Corporation. He had first heard of the technique directly from Osterberg when the two were seated together on a return flight from a project for which both had consulted, and he assured his seatmate that he could make a cell that would work on driven piles. He did, and thus earned a seat at that 1990 meeting in Aurora.

The next significant commercial application came on the Port Orange Bridge project in Florida in 1988. The geotechnical consultants on that project, John Schmertmann and David Crapps, knew of Osterberg's test method and set up a program to compare it to a conventional top-down load test. Following this successful application, the two men decided to set up the Aurora meeting. At the time, Schmertmann knew that Pedro da Silva in Brazil had developed a similar bi-directional test and invited him to the meeting as well. I was the fifth invitee.

Life Savings Surprise

From its inception, Osterberg had worked hard to get the geotechnical engineering profession to try the new test method, mostly through academic conferences and papers. However, after six years of promoting, he had little to show for his efforts. So, imagine his surprise that some of us offered to put up our life savings to start a venture based on his invention. We struck the deal at that meeting and Loadtest Inc. was born; a company dedicated to using and developing the Osterberg Cell test and to becoming a world leader in deep foundation testing

AUTHOR:

Jack A. Hayes, President, Loadtest Inc.

technology and services. These were lofty goals for a company with a staff of two and a one-room office. The name of the new company did not come easily. After much brainstorming, it boiled down to two: ShaftTest Inc. and Loadtest Inc. The stalemate ended when the author suggested that most people would rather get "loaded" than "shafted."

The next three years became the period of "preaching in the wilderness." Although generally supportive of innovations, the engineering profession has not always embraced them easily. The fear of creative disruption of acquired "standard of practice" often makes engineers reluctant to try new technologies, especially if perceived as costly. Indeed, the cost of O-cell testing was not competitive with conventional tests until test loads exceeded 1,000 tons (8.8 MN). At this time, agencies in the U.S. did not require or specify load tests exceeding 1,000 tons (8.8 MN), the practical limit for conventional top down tests. A market survey had suggested a potential annual demand of about ten 1,000 ton (8.8 MN) load tests.

In its second year of operation, Loadtest carried out 8 O-cell tests, most well in excess of 1,000 tons (8.8 MN). Things literally got shaken up, however, at the L.A. Coliseum during the 1994 Northridge earthquake. The foundation retrofit after this quake ended up requiring twenty-eight 2,000 ton (17.7 MN) O-cell tests. Since we tested every drilled shaft on the project, it became a landmark in the foundation industry: the first example of a drilled shaft foundation designed with a 0.9 resistance factor. This project marked a turning point in the quest to create a market for the O-cell test. No more wandering in the wilderness.

Dramatic Improvements

The very busy years after 1995 resulted in dramatic improvements in the O-cell test process. Displacement transducers replaced dial gages; every shaft had vibrating wire strain devices attached to the re-bar cage; manual controls gave way to automated systems run by software. This led to an observation by Dr. Bengt Fellenius that Loadtest carried out O-cell tests to a "research level quality." This outcome was

The Osterberg Cell: A Truly Great Contribution

I first heard about the O-cell test in the mid-1980s when Jorj Osterberg told me about his innovation, which consisted of placing a sacrificial jack at the toe of a pile and letting it simultaneously push upward and downward to a load equal to the intended working load on the pile head. He thus obtained a factor of safety of 2.0 in the test, eliminating the need to supply and build-up reaction weight for the test. I soon realized that Jorj's innovation is one of the truly great contributions to geotechnical engineering. Indeed, working with O-cell results has significantly developed the understanding and knowledge about the static loading test and the response of piles to load from a structure—not just for me, but also for many others in the field. Here are just a few of the key lessons we have learned.

1. Any before-the-test locked-in load (residual load) is measured, eliminating the need for its "guesstimation."
2. The routinely incorporated strain-gage instrumentation has shown many previously held beliefs about pile-soil response to load to be incorrect. One of them being that a pile toe would have an ultimate resistance. The wealth of O-cell tests performed have shown that a pile toe responds to increasing load by a more or less smooth load-movement curve that does not trend to an ultimate value.
3. For bored piles and drilled shafts, the test provides the ability to prove whether or not clean-up and removal of debris from the bottom of the shaft has been successful.
4. It is entirely feasible to use the O-cell as a construction device to prestress the pile toe and reduce the settlement for the foundation placed on that pile—and reduce construction time and foundation costs.
5. While the test can be carried out per any desired schedule of testing, it has been very instrumental in teaching the geotech community that the best test data for analysis are obtained by a test incorporating many short increments applied at same-length time intervals and excluding unloading/reloading 'cycles' during the test.
6. If the test would not engage the shaft fully, but only the pile toe, then, it is simple and economical to arrange for a supplemental head-down test to push the shaft with the O-cell open. This will ensure that shaft and toe responses are not just separately engaged, and that both responses are determined at large movements.
7. The positive measurements of the pile toe response enable designers to determine the long-term foundation settlement due to the pile working load and to the influence of the settlement of the surrounding ground. Therefore, the test is exceptionally useful for assessing the long-term settlement of the piled foundation represented by the test pile.

The O-cell test is now an established tool for the geotechnical engineering industry, and major projects around the world have applied it for the design of large and small foundations. There is rarely a geotechnical conference that does not include at least one case history paper describing results and lessons learned from O-cell tests.

Bengt H. Fellenius, Consulting Engineer hastened by the fact that Loadtest had become a company focused primarily on O-cell testing, a unique situation in the foundation industry. Conventional deep foundation testing had always been a sideline of engineering or construction firms. Eventually automation, along with the Internet, led to setting up tests in the remote tar sands of Alberta and in places like Tajikistan in central Asia, and then running the tests (controlling pumps and valves plus collecting data) from the comfort of the office in Gainesville, Fla.

Most of the publicity for the O-cell test has been about its ability to apply and measure high loads. Almost from the beginning, O-cell tests broke existing loading records. A test on one of the drilled shafts in the main pier of the William H. Natcher Bridge, Owensboro, Ky., produced a nominal loading of 6,000 tons (53 MN) in 1993.

The following table illustrates the progression of record loading since that time.

World Record Osterberg Cell Load Tests

2010	**Mississippi River Bridge, St. Louis, MO**	**36,067 tons (321 MN)**
2010	**Incheon 2nd Link, Incheon, Korea**	**31,350 tons (279 MN)**
2003	**Pomeroy OH - Mason WV, Ohio River**	**18,400 tons (163 MN)**
2006	**Amelia Earhart Bridge Kansas City, KS**	**17,800 tons (158 MN)**
2001	**Tucson, AZ**	**17,000 tons (151 MN)**
2002	**San Francisco**	**16,500 tons (146 MN)**
1997	**Apalachicola River, FL**	**15,000 tons (135 MN)**

The ability to determine the ultimate capacity of drilled shafts capable of carrying very high loads, especially in rock sockets, led to the following discovery. This measured relationship between design engineers assumed or estimated ultimate capacity (E) and the actual measured capacity (M) showed clearly that such estimates had almost always missed the mark on the low side. We usually explain this underestimating of foundation capacity as a natural reaction of geotechnical engineers to the uncertainty inherent in dealing with natural materials.

Paradoxically, however, the data showed that the stronger the founding material, the more conservative engineers became. We believe that most of this behavior stems from the fact that prior to the O-cell test no one had ever actually measured such high capacities for bored piles. This new knowledge and better understanding of potential pile capacity unleashed a torrent of cost-saving foundation re-designs that typically provided savings in the range of 10 to 20 times the cost of the related O-cell test. According to Jim Cahill, vice president of the Case Foundation Division of Keller Industries, "Use of the O-cell was the best thing that ever happened to the drilled shaft industry in that it gave us a way to prove the value of our product to … Departments of Transportation."

Figure 2 illustrates another major technical achievement of the O-cell method; the bi-directional nature of the

Workers checking O-cells at the Incheon bridge site

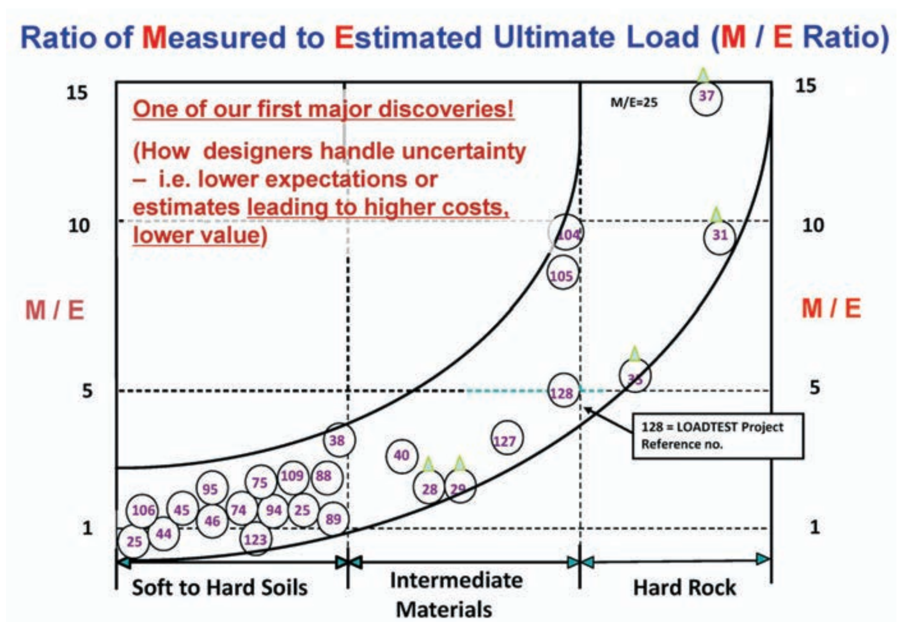

Figure 1. M/E ratio

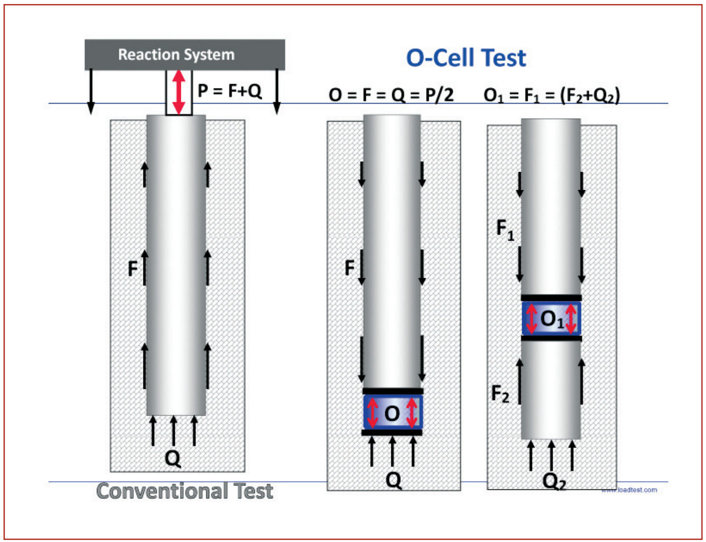

Figure 2. Illustrating the bi-directional nature of the O-cell test

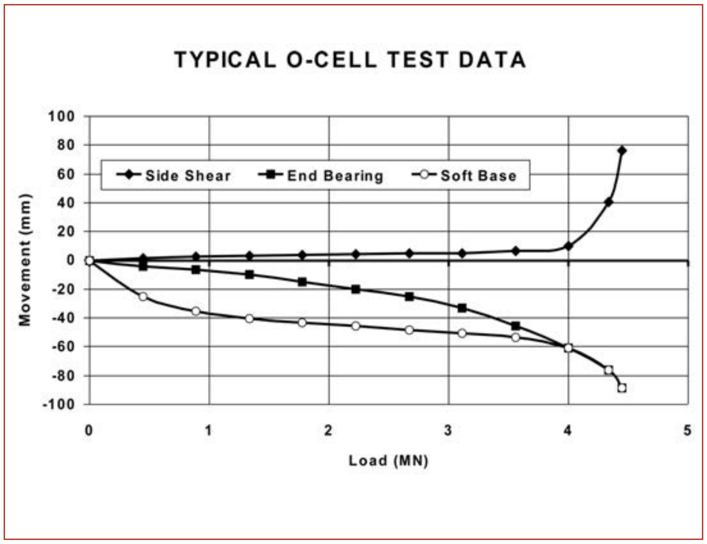

Figure 3. Typical O-cell test results

test allows the separation and direct measurement of the side shear and end bearing components of drilled shaft capacity.

As shown in Figure 3, the test provides a unique load-movement curve for side shear resistance and for end bearing capacity. Properly combining these load-movement data produces an equivalent top load curve that would result from a conventional static load test. Since geotechnical engineers typically use estimated side shear and end bearing parameters for the design of drilled shafts, actually measuring these components directly in an O-cell test, greatly simplifies the analysis and checking process.

Although designers have struggled with the uncertainties in dealing with subsurface ground conditions, they also have to deal with the impact of construction technique and quality on drilled shaft capacity. The data from O-cell testing suggests that construction issues account for about 50% of the uncertainty about drilled shaft capacity.

Back in 2003, we presented (at a DFI conference in Florida) the results of O-cell tests indicating that improper techniques can reduce either side shear or end bearing capacity by as much as 70% to 80%. In the past, such losses did not show up in conventional testing since rarely did both side shear and end bearing losses occur simultaneously. (We don't worry about what we can't see or measure.)

Replacing Guesswork

In the early planning stages for this Landmarks Issue of *Deep Foundations,* Editor Virginia Fairweather called and asked what I thought was the most important development in drilled shafts. I didn't hesitate to tell her that the Osterberg load cell test was the clear standout. I remember my early days of drilled shaft designs, where the process of estimating values for side shear and end bearing was mostly judgment, derived from a comparison of the rock at the site to the New York City Building Code, which was bold enough to codify a value of 200 psi allowable side shear for caissons in the NYC bedrock. (The NYC Department of Buildings based their value on a single test made in the late 1930s on a single 12 in (30 cm) diameter test shaft in Manhattan.) I remember trying to convince others who were not from New York that such values were acceptable in the same type of rock. I was generally unsuccessful.

In reality, we never really knew what the actual side shear and end bearing values would be at any particular site and just hoped that we were close enough without being too low or too high.

The Osterberg load cell test changed all that. Engineers now have the capability to measure side shear and end bearing in any drilled shaft. The O-cell test has enabled cost-effective designs by replacing guesswork with confidence. It's always been a pleasure working with Jack Hayes and the Loadtest staff. Their firm has greatly contributed to the advancement of drilled shafts, not only through the use of the test, but especially by making their database of tests results available to researchers, when the research will benefit the industry, but not for personal gain. I hope that more papers will be written on the subject of regionally-specific test results for certain rock formations, fully calibrated for LRFD. The next landmark for drill shafts might just well be a better method for testing and designing rock sockets for large lateral loads.

I also remember my pleasure meeting Dr. Osterberg for the first time, when I became chair of the DFI Drilled Shafts Committee. He was an enthusiastic committee member, willing to listen to new ideas from the young guys and happy to share his experience. Once, he told me his father had wanted him to become a medical doctor and he considered it for a while. I am glad he chose our profession instead.

Fred Rhyner, Senior Associate, Mueser Rutledge Consulting Engineers

After 20 years of O-cell testing experience, engineers at Loadtest realize that our function within the industry has evolved from simple load testing to a role better described as "risk mitigators." The advent of the LRFD design approach has made us all more aware of the importance of estimating and determining the ultimate capacity of deep foundations. We also realize how much of the risk related to foundation design has been covered by the designer's use of conservative (meaning low) resistance factors. Clearly the only way to increase these resistance factors requires more certainty, which means more testing (of all kinds, both pre-design and during construction). As we pointed out in ASCE's *Schmertmann Volume,* the designer can estimate the cost of risk in an LRFD design by comparing the cost of two hypothetical designs, one with code allowable resistance parameters and a standard RF of 0.4 against another with higher estimated resistance parameters and an RF of 1.0. The cost differential between these hypothetical designs provides a reasonable assessment of the cost of risk and uncertainty associated with the project. Our experience suggests that this "cost of risk" will exceed 40% to 60% of the total deep foundation cost. On larger projects, this can amount to many millions of dollars. If this is pointed out to the owner agency, it should be willing to spend at least 50% of the "cost of risk" to provide more certainty and a safer foundation. Paradoxically, this approach would also lead to a less expensive foundation.

Risk and Uncertainty

This brings us again to another period of preaching in the wilderness. We need to convince designers that good engineering should strive for certainty and not rely on the false comfort provided by using conservative resistance factors to cover up risk and uncertainty. Achieving complete certainty in the capacity of drilled shaft foundations can happen if we embrace the concept of complete and careful testing. The future may find an O-cell, or something equivalent, in every drilled shaft. Jorj Osterberg would have liked to see that.

Osterberg: A Passion for the Profession

Dr. Jorg Osterberg was a rare individual who combined great technical skill, innovative ideas, and a passion and enthusiasm for his profession. The "O-cell" may be the innovation for which he is best remembered. Thanks to him, it is possible to make direct measurements of load-carrying capacity of drilled shafts in rock at load magnitudes that exceed any practical testing method in existence before the O-cell. In the past, high capacity drilled shafts were typically designed on the basis of presumptive values of bearing capacity, with little ability for verification by design engineers. The effect of construction methods on capacity was poorly understood, and drilled shafts in rock were typically treated as rock-bearing footings with frequent use of the dangerous practice of direct down-hole inspection by the engineer. The O-cell approach to load testing has truly revolutionized the way we do business in the drilled shaft industry. Engineers are able to develop more efficient designs. The effects of different construction techniques on performance can be measured and evaluated. The ability to make direct measurements of performance of high capacity foundations is a key component of performance-based specifications, particularly with alternative project delivery methods such as design-build.

Dr. Osterberg's O-cell is one of those great inventions that provide us all with a step up to build from, and spawns further innovation to improve our industry and our profession. He represented the best of the American can-do spirit of hard work plus creativity, and his O-cell is a proud legacy of this great engineer.

Dan Brown, Dan Brown and Associates, PC

This setup was for a 10,000 ton (88 MN) test on a barrette in St. Petersburg, Russia