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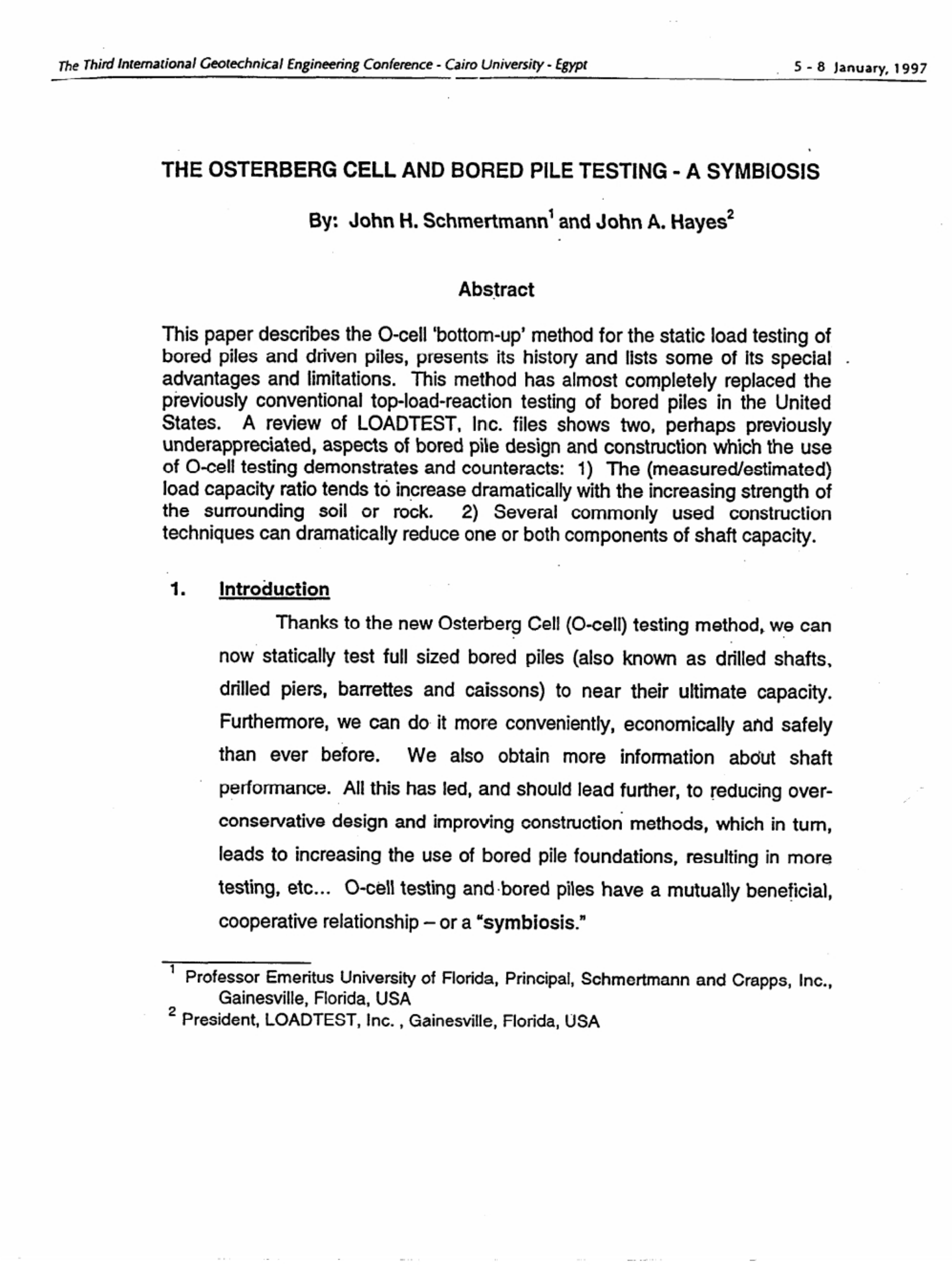

The Third International Geotechnical Engineering Conference - Cairo University - Egypt 5 - 8 January, 1997

THE OSTERBERG CELL AND BORED PILE TESTING - A SYMBIOSIS

By: John H. Schmertmann[1] and John A. Hayes[2]

Abstract

This paper describes the O-cell 'bottom-up' method for the static load testing of bored piles and driven piles, presents its history and lists some of its special advantages and limitations. This method has almost completely replaced the previously conventional top-load-reaction testing of bored piles in the United States. A review of LOADTEST, Inc. files shows two, perhaps previously underappreciated, aspects of bored pile design and construction which the use of O-cell testing demonstrates and counteracts: 1) The (measured/estimated) load capacity ratio tends to increase dramatically with the increasing strength of the surrounding soil or rock. 2) Several commonly used construction techniques can dramatically reduce one or both components of shaft capacity.

1. Introduction

Thanks to the new Osterberg Cell (O-cell) testing method, we can now statically test full sized bored piles (also known as drilled shafts, drilled piers, barrettes and caissons) to near their ultimate capacity. Furthermore, we can do it more conveniently, economically and safely than ever before. We also obtain more information about shaft performance. All this has led, and should lead further, to reducing over-conservative design and improving construction methods, which in turn, leads to increasing the use of bored pile foundations, resulting in more testing, etc... O-cell testing and bored piles have a mutually beneficial, cooperative relationship – or a **"symbiosis."**

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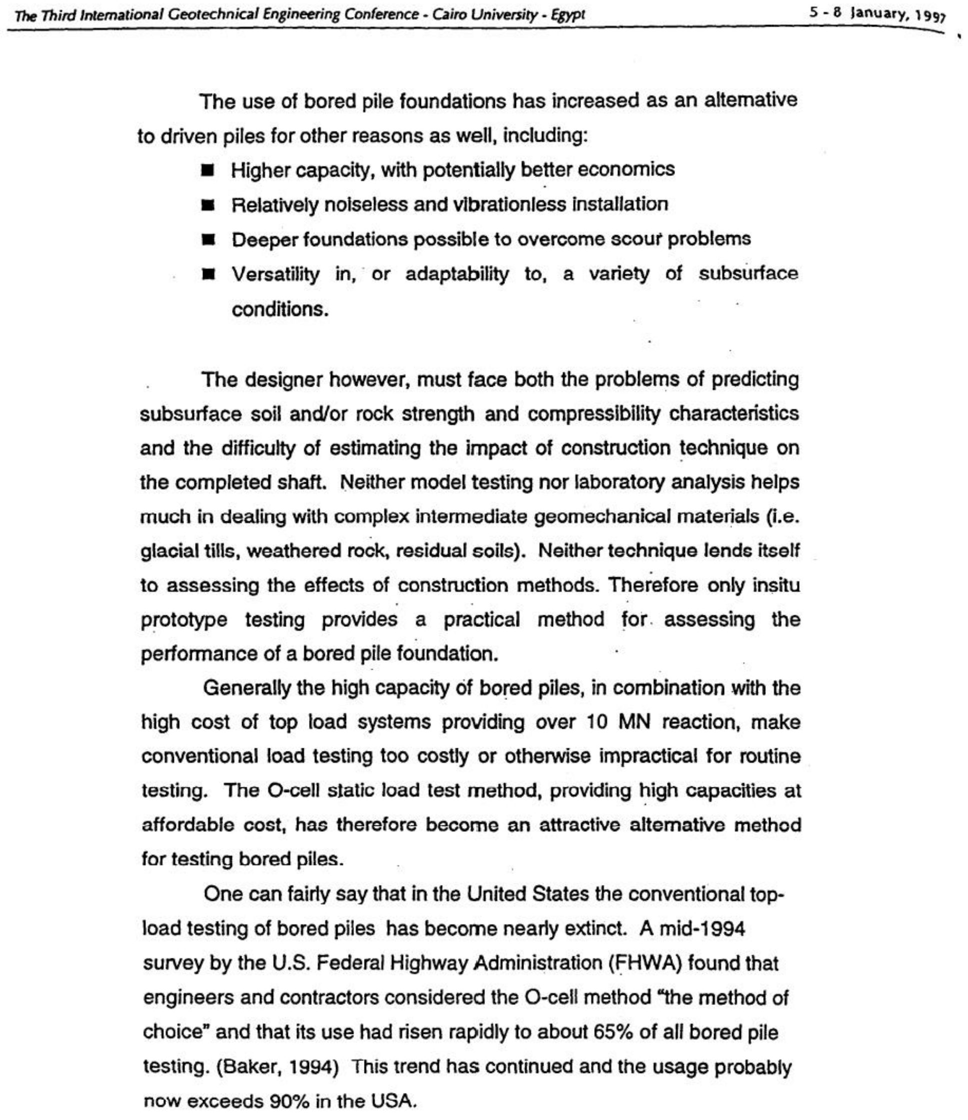


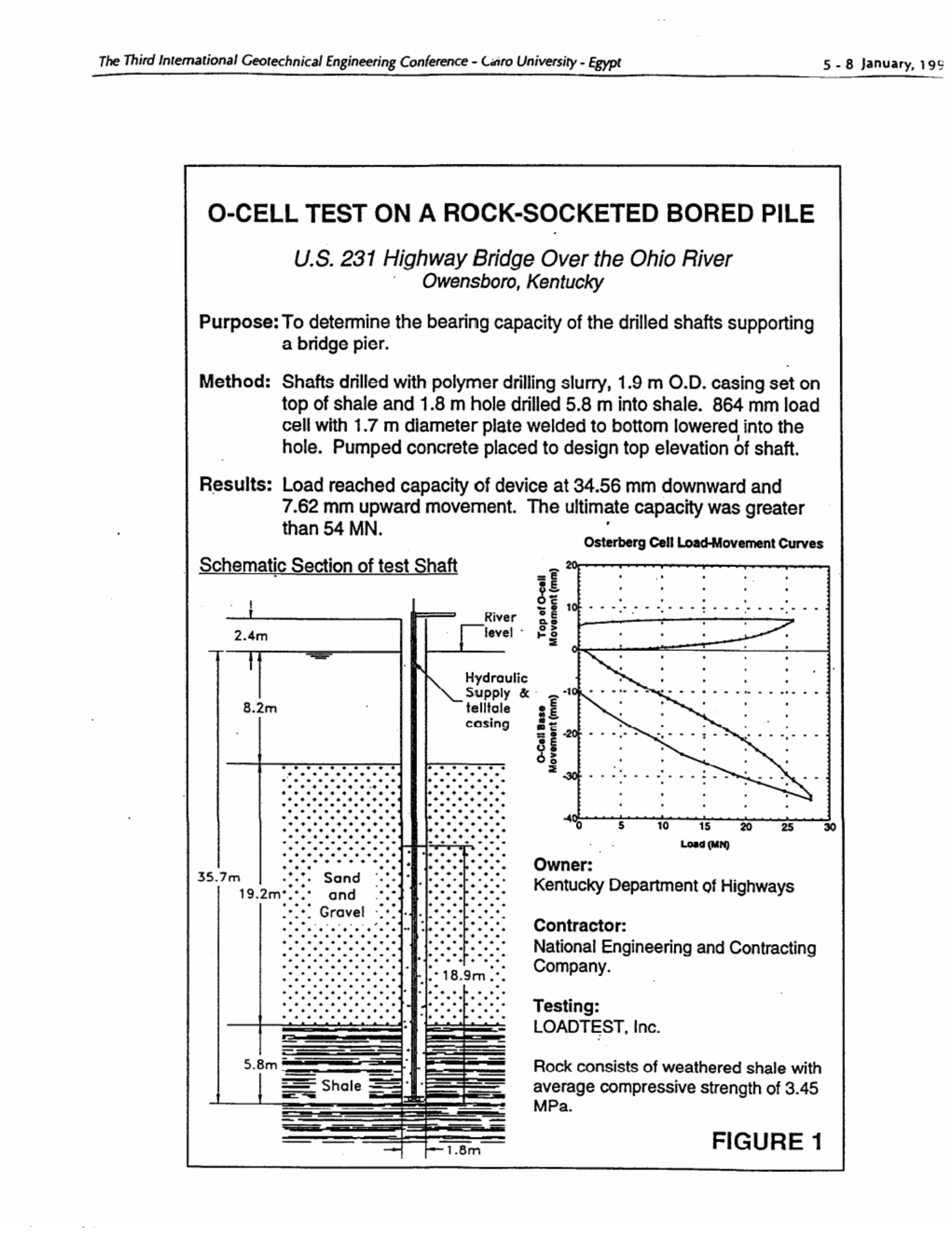
The use of bored pile foundations has increased as an alternative to driven piles for other reasons as well, including:

- Higher capacity, with potentially better economics
- Relatively noiseless and vibrationless installation
- Deeper foundations possible to overcome scour problems
- Versatility in, or adaptability to, a variety of subsurface conditions.

The designer however, must face both the problems of predicting subsurface soil and/or rock strength and compressibility characteristics and the difficulty of estimating the impact of construction technique on the completed shaft. Neither model testing nor laboratory analysis helps much in dealing with complex intermediate geomechanical materials (i.e. glacial tills, weathered rock, residual soils). Neither technique lends itself to assessing the effects of construction methods. Therefore only insitu prototype testing provides a practical method for assessing the performance of a bored pile foundation.

Generally the high capacity of bored piles, in combination with the high cost of top load systems providing over 10 MN reaction, make conventional load testing too costly or otherwise impractical for routine testing. The O-cell static load test method, providing high capacities at affordable cost, has therefore become an attractive alternative method for testing bored piles.

One can fairly say that in the United States the conventional top-load testing of bored piles has become nearly extinct. A mid-1994 survey by the U.S. Federal Highway Administration (FHWA) found that engineers and contractors considered the O-cell method "the method of choice" and that its use had risen rapidly to about 65% of all bored pile testing. (Baker, 1994) This trend has continued and the usage probably now exceeds 90% in the USA.



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O-CELL TEST ON A ROCK-SOCKETED BORED PILE

U.S. 231 Highway Bridge Over the Ohio River
Owensboro, Kentucky

Purpose: To determine the bearing capacity of the drilled shafts supporting a bridge pier.

Method: Shafts drilled with polymer drilling slurry, 1.9 m O.D. casing set on top of shale and 1.8 m hole drilled 5.8 m into shale. 864 mm load cell with 1.7 m diameter plate welded to bottom lowered into the hole. Pumped concrete placed to design top elevation of shaft.

Results: Load reached capacity of device at 34.56 mm downward and 7.62 mm upward movement. The ultimate capacity was greater than 54 MN.

Schematic Section of test Shaft

Osterberg Cell Load-Movement Curves

Owner:
Kentucky Department of Highways

Contractor:
National Engineering and Contracting Company.

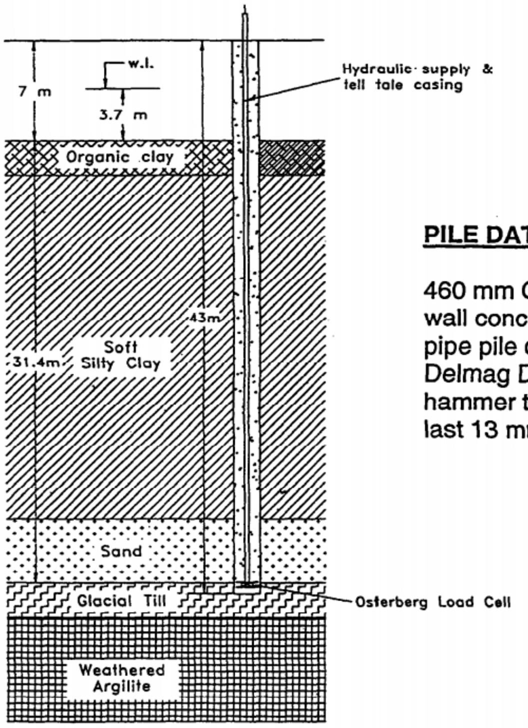
Testing:
LOADTEST, Inc.

Rock consists of weathered shale with average compressive strength of 3.45 MPa.

FIGURE 1

O-CELL TEST ON A DRIVEN PILE

Pines River Bridge
Massachusetts



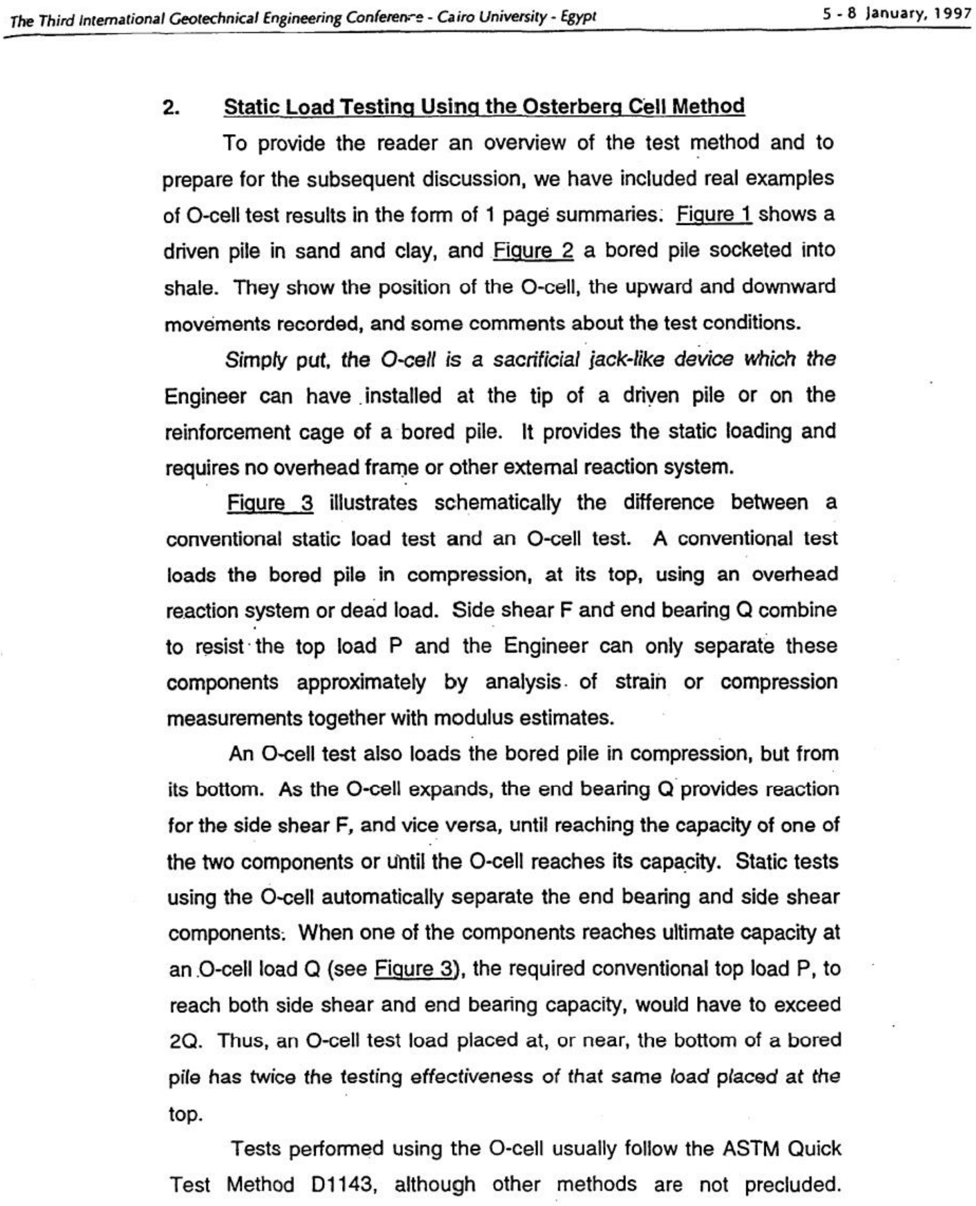
PILE DATA

460 mm O.D. 13 mm. wall concrete filled pipe pile driven with a Delmag D36-13 hammer to 10 blows last 13 mm.

TEST RESULTS

Peak load = 1.9 MN (7.62 mm movement at failure)
Skin friction = 36.9 kPa.
End bearing = 11.7 MPa (2.03 mm movement)
Ultimate pile load capacity > 3.80 MN

FIGURE 2



2. Static Load Testing Using the Osterberg Cell Method

To provide the reader an overview of the test method and to prepare for the subsequent discussion, we have included real examples of O-cell test results in the form of 1 page summaries. Figure 1 shows a driven pile in sand and clay, and Figure 2 a bored pile socketed into shale. They show the position of the O-cell, the upward and downward movements recorded, and some comments about the test conditions.

Simply put, the O-cell is a sacrificial jack-like device which the Engineer can have installed at the tip of a driven pile or on the reinforcement cage of a bored pile. It provides the static loading and requires no overhead frame or other external reaction system.

Figure 3 illustrates schematically the difference between a conventional static load test and an O-cell test. A conventional test loads the bored pile in compression, at its top, using an overhead reaction system or dead load. Side shear F and end bearing Q combine to resist the top load P and the Engineer can only separate these components approximately by analysis of strain or compression measurements together with modulus estimates.

An O-cell test also loads the bored pile in compression, but from its bottom. As the O-cell expands, the end bearing Q provides reaction for the side shear F, and vice versa, until reaching the capacity of one of the two components or until the O-cell reaches its capacity. Static tests using the O-cell automatically separate the end bearing and side shear components. When one of the components reaches ultimate capacity at an O-cell load Q (see Figure 3), the required conventional top load P, to reach both side shear and end bearing capacity, would have to exceed 2Q. Thus, an O-cell test load placed at, or near, the bottom of a bored pile has twice the testing effectiveness of that same load placed at the top.

Tests performed using the O-cell usually follow the ASTM Quick Test Method D1143, although other methods are not precluded.

COMPARISON OF 0-CELL AND CONVENTIONAL TESTS

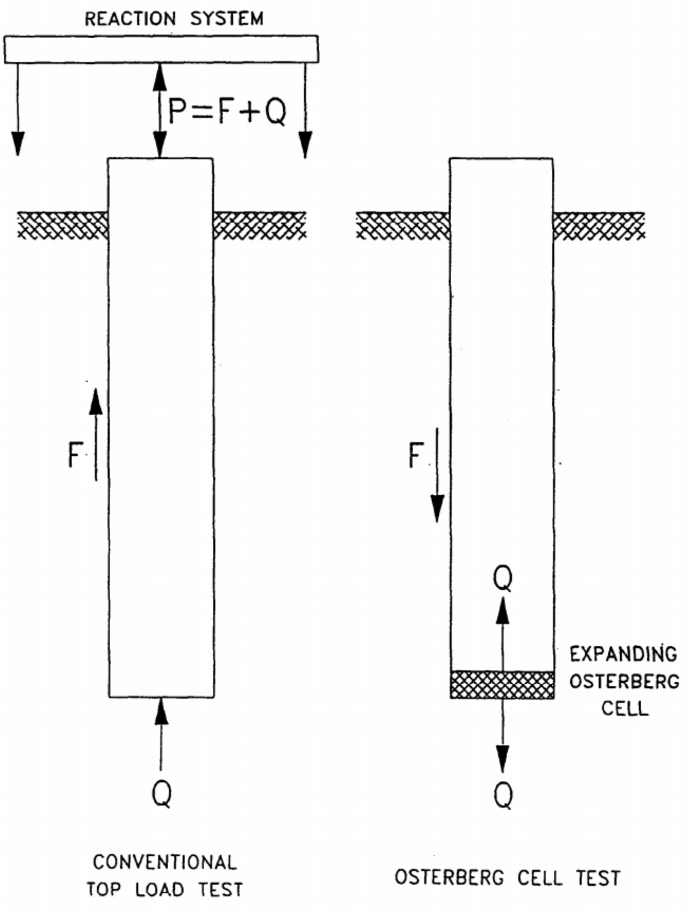
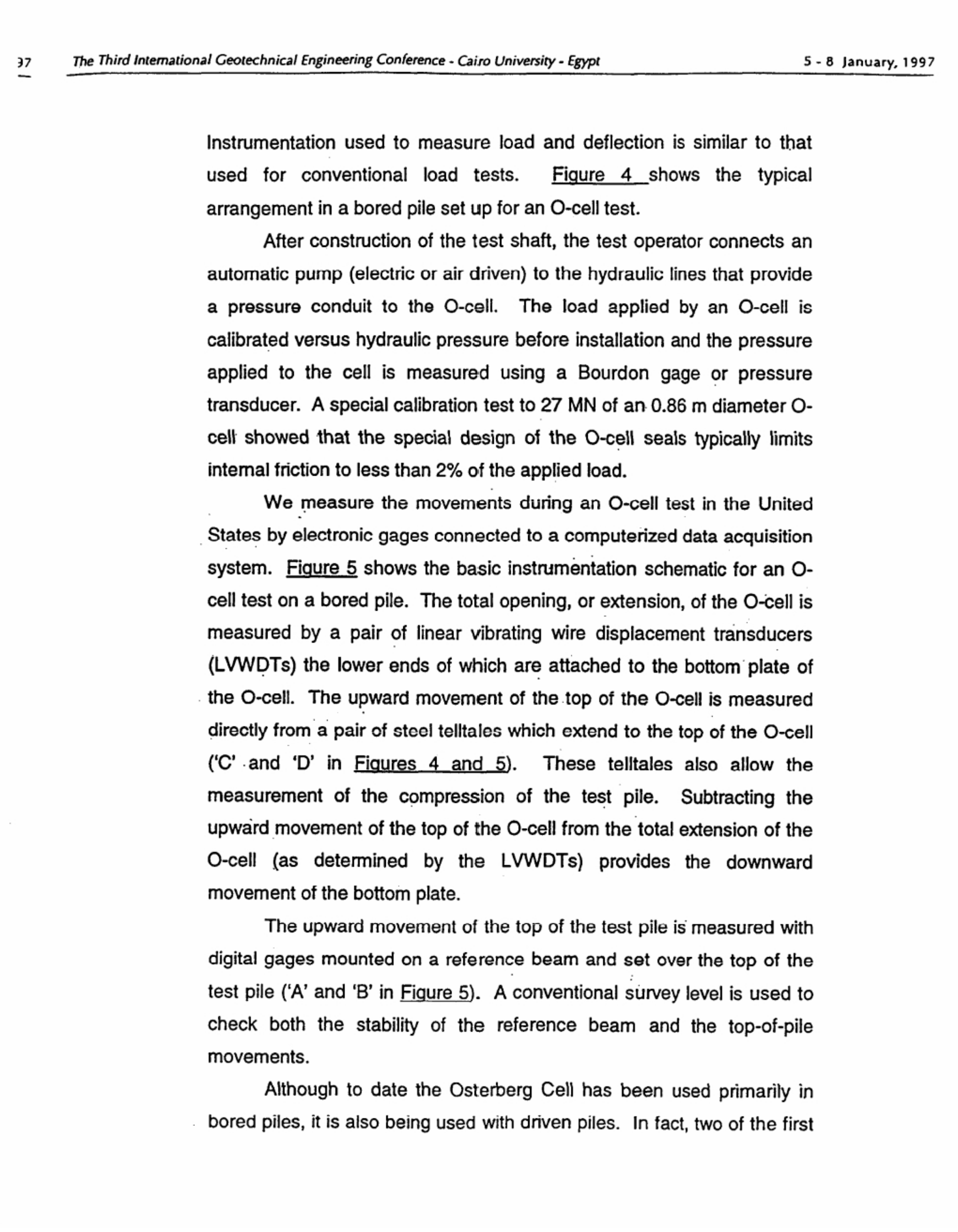


FIGURE 3



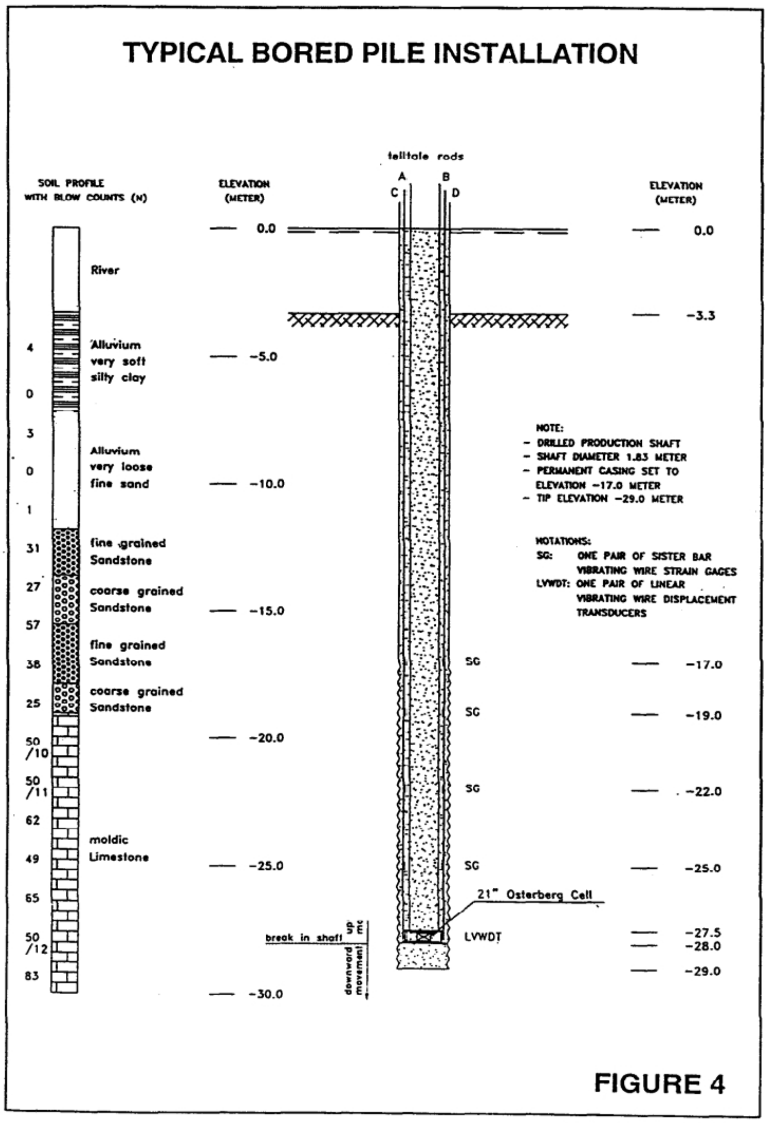
Instrumentation used to measure load and deflection is similar to that used for conventional load tests. Figure 4 shows the typical arrangement in a bored pile set up for an O-cell test.

After construction of the test shaft, the test operator connects an automatic pump (electric or air driven) to the hydraulic lines that provide a pressure conduit to the O-cell. The load applied by an O-cell is calibrated versus hydraulic pressure before installation and the pressure applied to the cell is measured using a Bourdon gage or pressure transducer. A special calibration test to 27 MN of an 0.86 m diameter O-cell showed that the special design of the O-cell seals typically limits internal friction to less than 2% of the applied load.

We measure the movements during an O-cell test in the United States by electronic gages connected to a computerized data acquisition system. Figure 5 shows the basic instrumentation schematic for an O-cell test on a bored pile. The total opening, or extension, of the O-cell is measured by a pair of linear vibrating wire displacement transducers (LVWDTs) the lower ends of which are attached to the bottom plate of the O-cell. The upward movement of the top of the O-cell is measured directly from a pair of steel telltales which extend to the top of the O-cell ('C' and 'D' in Figures 4 and 5). These telltales also allow the measurement of the compression of the test pile. Subtracting the upward movement of the top of the O-cell from the total extension of the O-cell (as determined by the LVWDTs) provides the downward movement of the bottom plate.

The upward movement of the top of the test pile is measured with digital gages mounted on a reference beam and set over the top of the test pile ('A' and 'B' in Figure 5). A conventional survey level is used to check both the stability of the reference beam and the top-of-pile movements.

Although to date the Osterberg Cell has been used primarily in bored piles, it is also being used with driven piles. In fact, two of the first



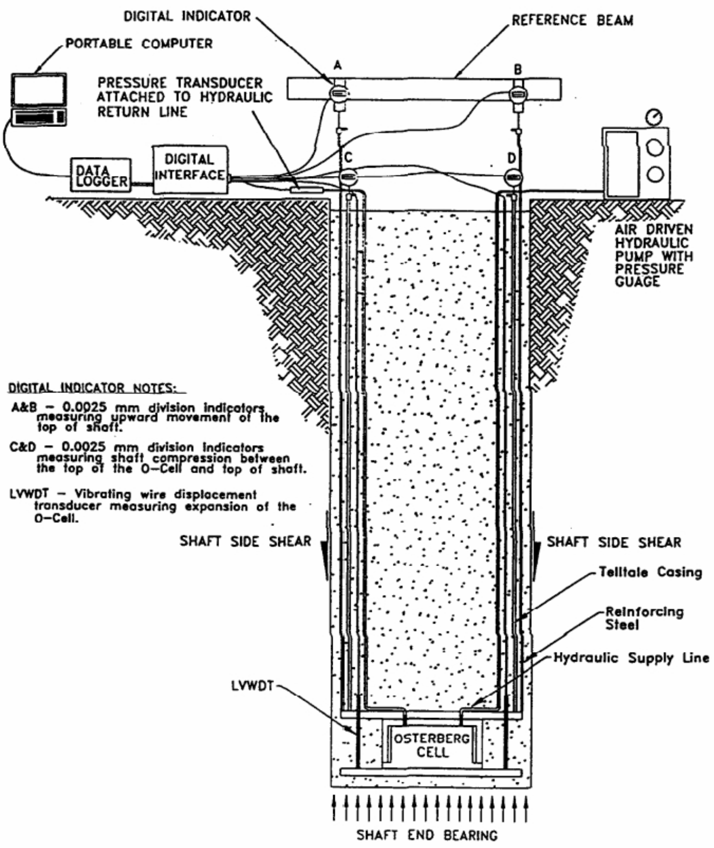
TYPICAL BORED PILE INSTALLATION

NOTE:
- DRILLED PRODUCTION SHAFT
- SHAFT DIAMETER 1.83 METER
- PERMANENT CASING SET TO ELEVATION −17.0 METER
- TIP ELEVATION −29.0 METER

NOTATIONS:
SG: ONE PAIR OF SISTER BAR VIBRATING WIRE STRAIN GAGES
LVWDT: ONE PAIR OF LINEAR VIBRATING WIRE DISPLACEMENT TRANSDUCERS

FIGURE 4

TYPICAL TEST INSTRUMENTATION



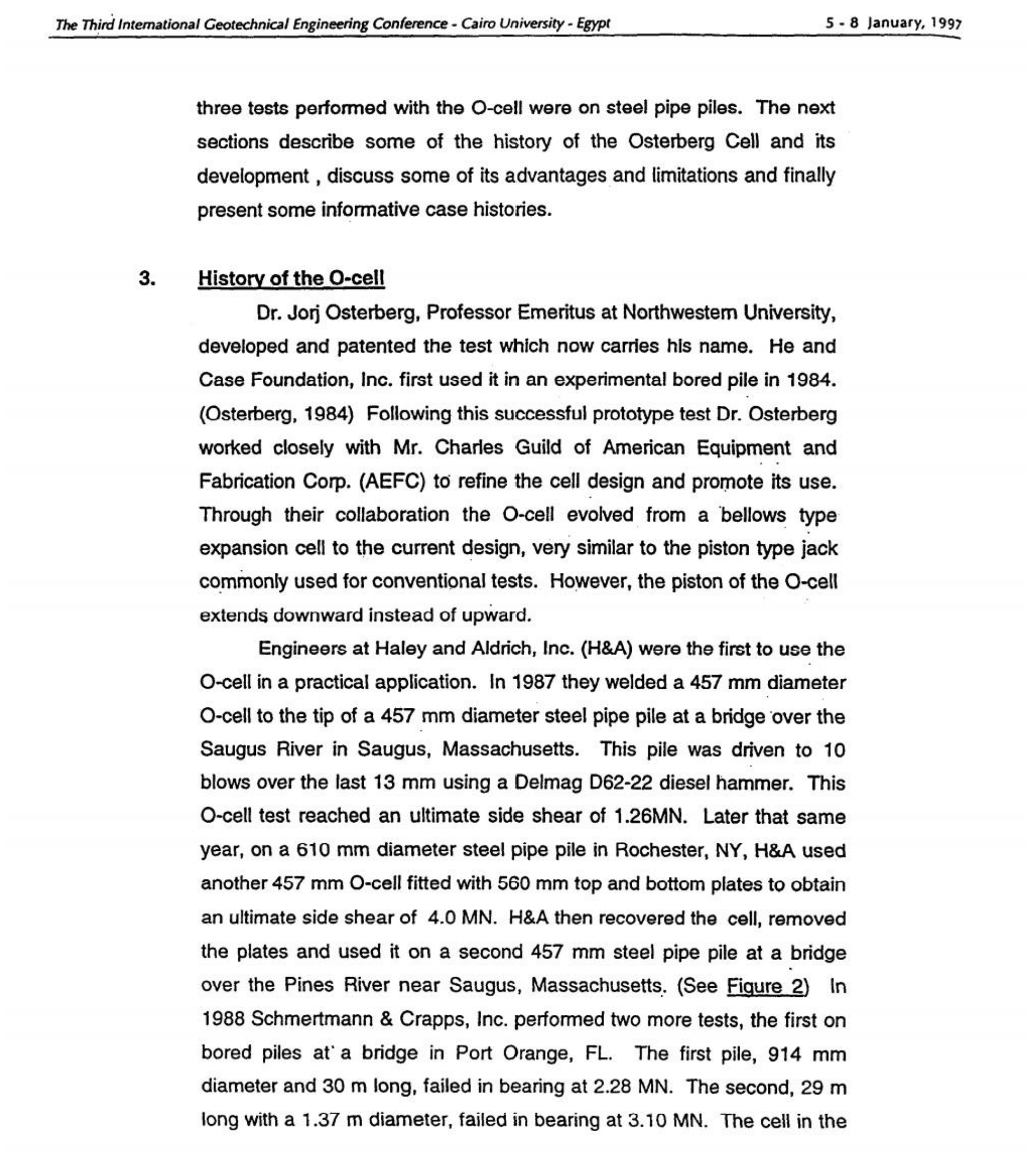
DIGITAL INDICATOR NOTES:

A&B – 0.0025 mm division indicators measuring upward movement of the top of shaft.

C&D – 0.0025 mm division indicators measuring shaft compression between the top of the O–Cell and top of shaft.

LVWDT – Vibrating wire displacement transducer measuring expansion of the O–Cell.

FIGURE 5

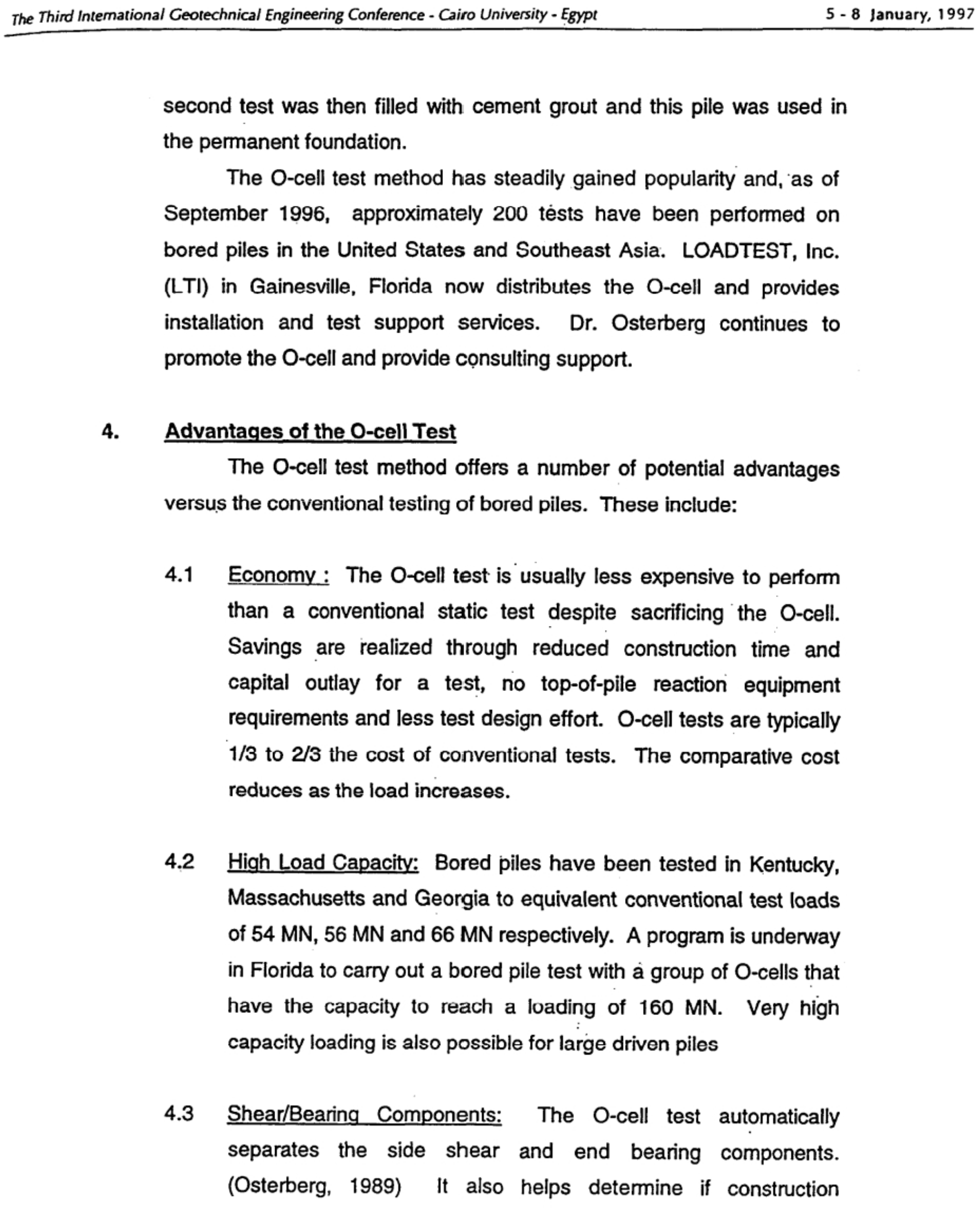


three tests performed with the O-cell were on steel pipe piles. The next sections describe some of the history of the Osterberg Cell and its development , discuss some of its advantages and limitations and finally present some informative case histories.

3. History of the O-cell

Dr. Jorj Osterberg, Professor Emeritus at Northwestern University, developed and patented the test which now carries his name. He and Case Foundation, Inc. first used it in an experimental bored pile in 1984. (Osterberg, 1984) Following this successful prototype test Dr. Osterberg worked closely with Mr. Charles Guild of American Equipment and Fabrication Corp. (AEFC) to refine the cell design and promote its use. Through their collaboration the O-cell evolved from a bellows type expansion cell to the current design, very similar to the piston type jack commonly used for conventional tests. However, the piston of the O-cell extends downward instead of upward.

Engineers at Haley and Aldrich, Inc. (H&A) were the first to use the O-cell in a practical application. In 1987 they welded a 457 mm diameter O-cell to the tip of a 457 mm diameter steel pipe pile at a bridge over the Saugus River in Saugus, Massachusetts. This pile was driven to 10 blows over the last 13 mm using a Delmag D62-22 diesel hammer. This O-cell test reached an ultimate side shear of 1.26MN. Later that same year, on a 610 mm diameter steel pipe pile in Rochester, NY, H&A used another 457 mm O-cell fitted with 560 mm top and bottom plates to obtain an ultimate side shear of 4.0 MN. H&A then recovered the cell, removed the plates and used it on a second 457 mm steel pipe pile at a bridge over the Pines River near Saugus, Massachusetts. (See Figure 2) In 1988 Schmertmann & Crapps, Inc. performed two more tests, the first on bored piles at a bridge in Port Orange, FL. The first pile, 914 mm diameter and 30 m long, failed in bearing at 2.28 MN. The second, 29 m long with a 1.37 m diameter, failed in bearing at 3.10 MN. The cell in the



second test was then filled with cement grout and this pile was used in the permanent foundation.

The O-cell test method has steadily gained popularity and, as of September 1996, approximately 200 tests have been performed on bored piles in the United States and Southeast Asia. LOADTEST, Inc. (LTI) in Gainesville, Florida now distributes the O-cell and provides installation and test support services. Dr. Osterberg continues to promote the O-cell and provide consulting support.

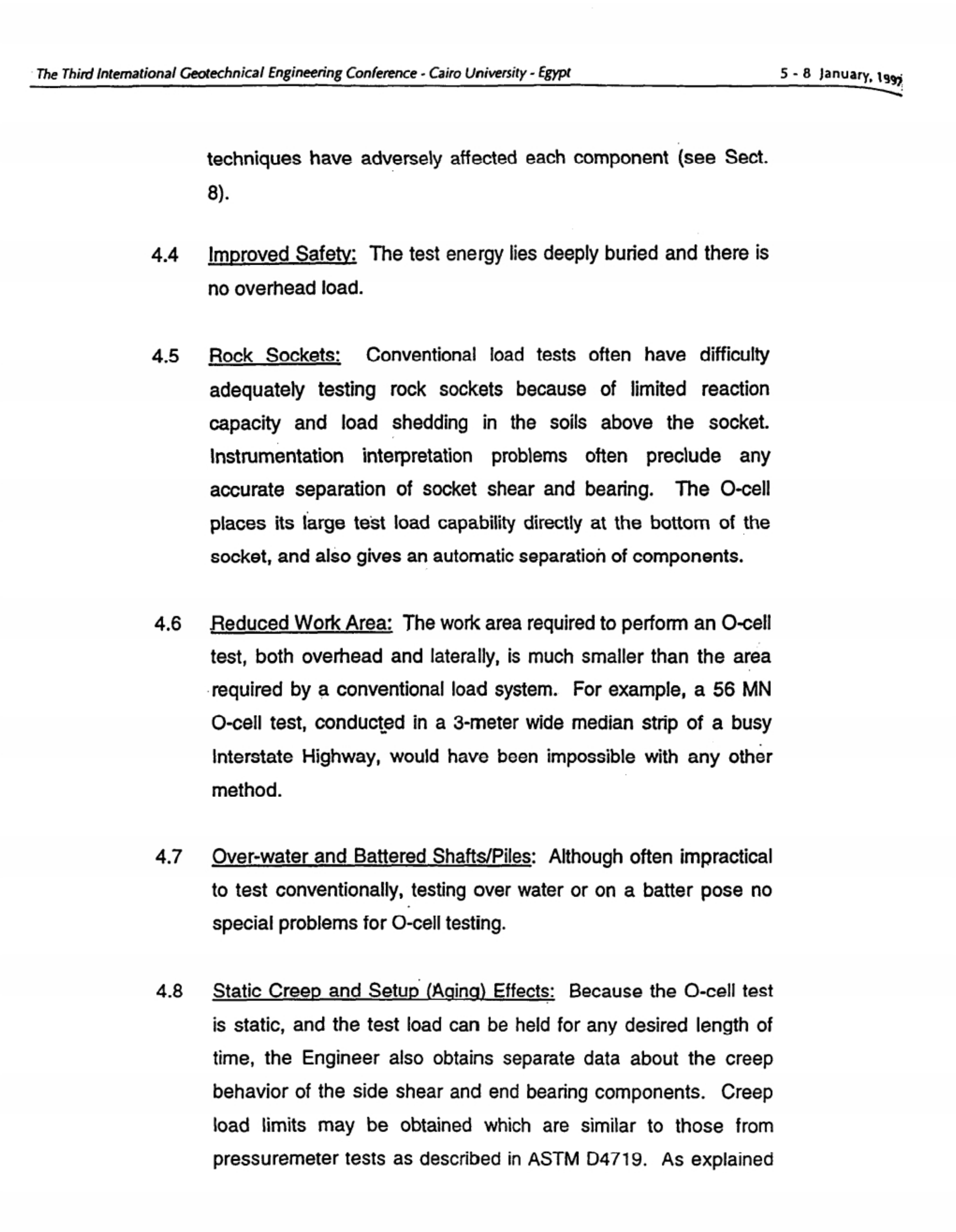
4. Advantages of the O-cell Test

The O-cell test method offers a number of potential advantages versus the conventional testing of bored piles. These include:

4.1 Economy : The O-cell test is usually less expensive to perform than a conventional static test despite sacrificing the O-cell. Savings are realized through reduced construction time and capital outlay for a test, no top-of-pile reaction equipment requirements and less test design effort. O-cell tests are typically 1/3 to 2/3 the cost of conventional tests. The comparative cost reduces as the load increases.

4.2 High Load Capacity: Bored piles have been tested in Kentucky, Massachusetts and Georgia to equivalent conventional test loads of 54 MN, 56 MN and 66 MN respectively. A program is underway in Florida to carry out a bored pile test with a group of O-cells that have the capacity to reach a loading of 160 MN. Very high capacity loading is also possible for large driven piles

4.3 Shear/Bearing Components: The O-cell test automatically separates the side shear and end bearing components. (Osterberg, 1989) It also helps determine if construction



techniques have adversely affected each component (see Sect. 8).

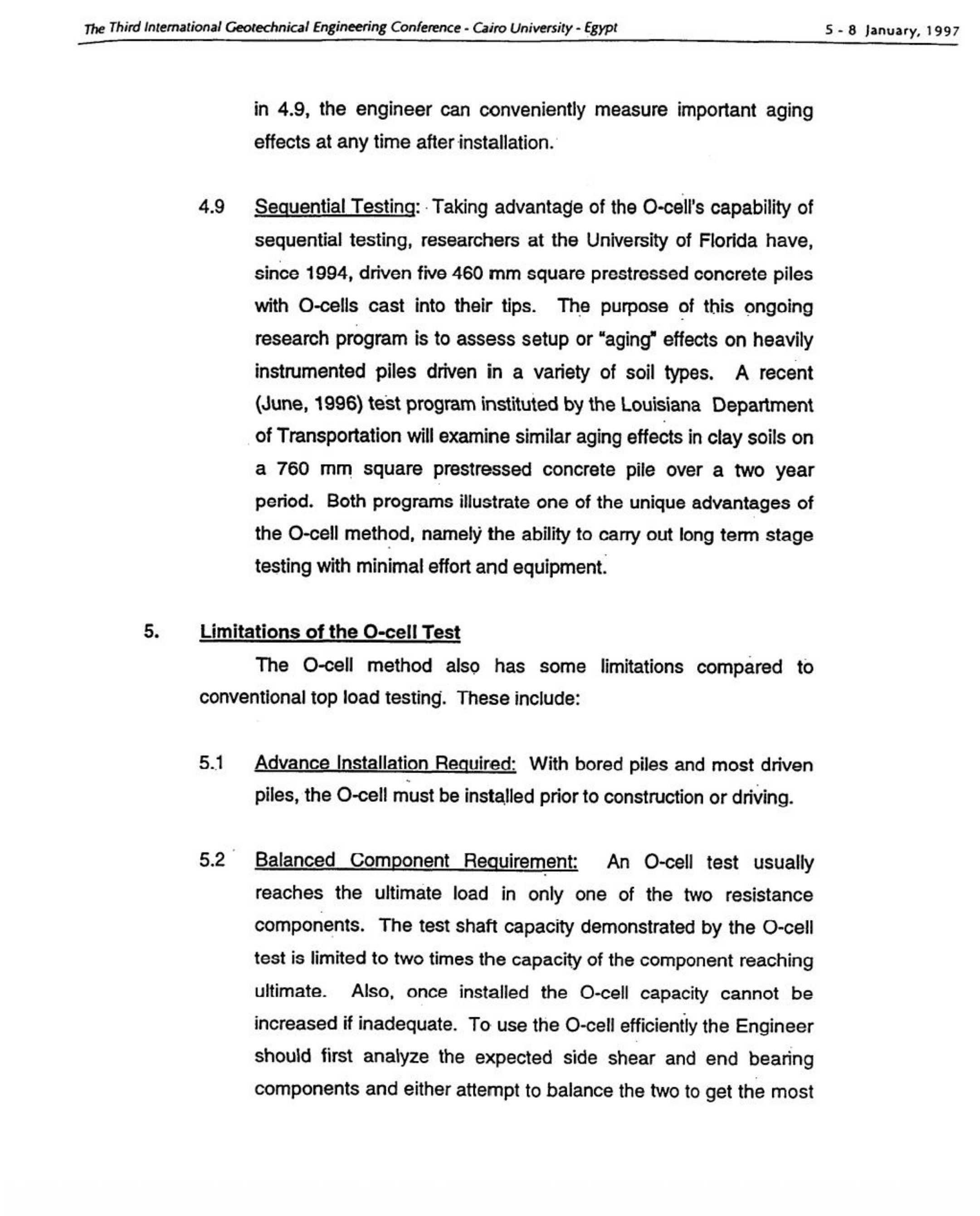
4.4 Improved Safety: The test energy lies deeply buried and there is no overhead load.

4.5 Rock Sockets: Conventional load tests often have difficulty adequately testing rock sockets because of limited reaction capacity and load shedding in the soils above the socket. Instrumentation interpretation problems often preclude any accurate separation of socket shear and bearing. The O-cell places its large test load capability directly at the bottom of the socket, and also gives an automatic separation of components.

4.6 Reduced Work Area: The work area required to perform an O-cell test, both overhead and laterally, is much smaller than the area required by a conventional load system. For example, a 56 MN O-cell test, conducted in a 3-meter wide median strip of a busy Interstate Highway, would have been impossible with any other method.

4.7 Over-water and Battered Shafts/Piles: Although often impractical to test conventionally, testing over water or on a batter pose no special problems for O-cell testing.

4.8 Static Creep and Setup (Aging) Effects: Because the O-cell test is static, and the test load can be held for any desired length of time, the Engineer also obtains separate data about the creep behavior of the side shear and end bearing components. Creep load limits may be obtained which are similar to those from pressuremeter tests as described in ASTM D4719. As explained



in 4.9, the engineer can conveniently measure important aging effects at any time after installation.

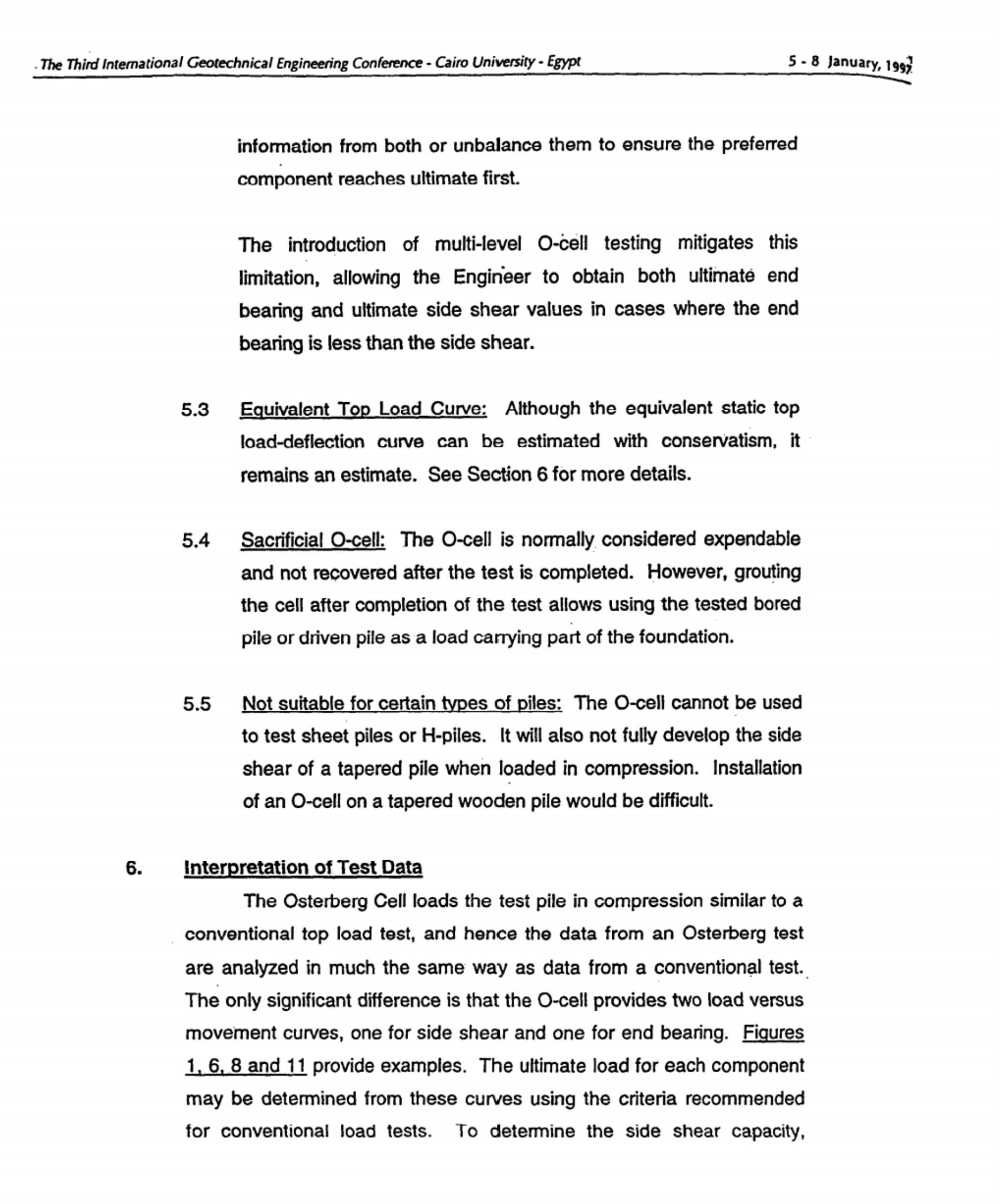
4.9 Sequential Testing: Taking advantage of the O-cell's capability of sequential testing, researchers at the University of Florida have, since 1994, driven five 460 mm square prestressed concrete piles with O-cells cast into their tips. The purpose of this ongoing research program is to assess setup or "aging" effects on heavily instrumented piles driven in a variety of soil types. A recent (June, 1996) test program instituted by the Louisiana Department of Transportation will examine similar aging effects in clay soils on a 760 mm square prestressed concrete pile over a two year period. Both programs illustrate one of the unique advantages of the O-cell method, namely the ability to carry out long term stage testing with minimal effort and equipment.

5. Limitations of the O-cell Test

The O-cell method also has some limitations compared to conventional top load testing. These include:

5.1 Advance Installation Required: With bored piles and most driven piles, the O-cell must be installed prior to construction or driving.

5.2 Balanced Component Requirement: An O-cell test usually reaches the ultimate load in only one of the two resistance components. The test shaft capacity demonstrated by the O-cell test is limited to two times the capacity of the component reaching ultimate. Also, once installed the O-cell capacity cannot be increased if inadequate. To use the O-cell efficiently the Engineer should first analyze the expected side shear and end bearing components and either attempt to balance the two to get the most



information from both or unbalance them to ensure the preferred component reaches ultimate first.

The introduction of multi-level O-cell testing mitigates this limitation, allowing the Engineer to obtain both ultimate end bearing and ultimate side shear values in cases where the end bearing is less than the side shear.

5.3 Equivalent Top Load Curve: Although the equivalent static top load-deflection curve can be estimated with conservatism, it remains an estimate. See Section 6 for more details.

5.4 Sacrificial O-cell: The O-cell is normally considered expendable and not recovered after the test is completed. However, grouting the cell after completion of the test allows using the tested bored pile or driven pile as a load carrying part of the foundation.

5.5 Not suitable for certain types of piles: The O-cell cannot be used to test sheet piles or H-piles. It will also not fully develop the side shear of a tapered pile when loaded in compression. Installation of an O-cell on a tapered wooden pile would be difficult.

6. Interpretation of Test Data

The Osterberg Cell loads the test pile in compression similar to a conventional top load test, and hence the data from an Osterberg test are analyzed in much the same way as data from a conventional test. The only significant difference is that the O-cell provides two load versus movement curves, one for side shear and one for end bearing. Figures 1, 6, 8 and 11 provide examples. The ultimate load for each component may be determined from these curves using the criteria recommended for conventional load tests. To determine the side shear capacity, subtract the buoyant weight of the test pile from the upward O-cell load. Note that the movement curve for end bearing does not include elastic pile compression because the load is applied directly.

The Engineer may further utilize the two component curves to construct an equivalent top load-deflection curve and thereby investigate the combined two-component pile capacity. Construction of the equivalent top load curve begins by determining the side shear at an arbitrary deflection point on the side shear-deflection curve. If the bored pile is assumed rigid, its top and bottom move together and have the same deflection at this load. By adding the side shear to the mobilized end bearing at the chosen deflection, one determines a single point on the equivalent top load curve. Additional points may then be calculated to develop the curve up to the maximum deflection (or maximum extrapolated deflection) of the component that did not reach ultimate value. Figure 7 presents such an equivalent top-load curve obtained from the test curves in Figure 6. In this case both components fortuitously reached near-ultimate simultaneously, which does not normally occur.

Points beyond the maximum deflection of the component that does not reach an ultimate may also be obtained by conservatively assuming that at greater deflections it remains constant at the maximum applied load. An example result using this method is shown on Figure 9, based on the O-cell curves in Figure 8. We also sometimes, but less conservatively, extrapolate the non-ultimate component by using hyperbolic curve fitting and then use this extrapolated curve in the calculations to produce the equivalent curve, as also shown on Figure 9 for comparison.

As noted by Osterberg (1994), the above construction makes the following three basic assumptions.

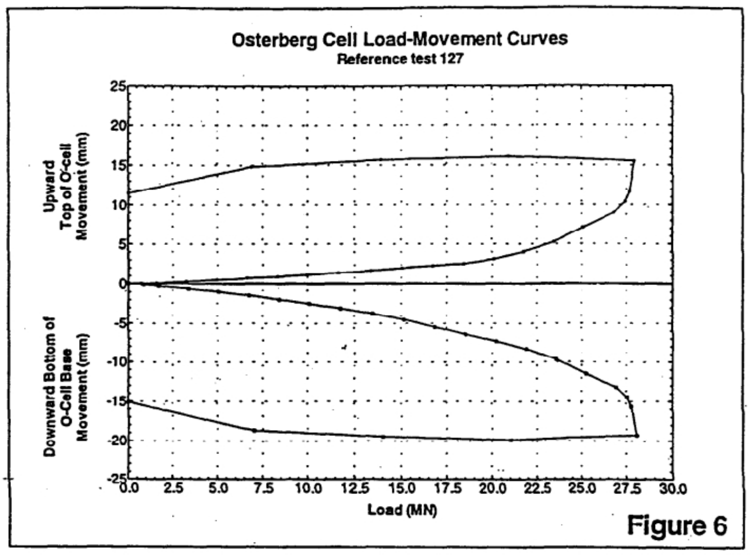


Figure 6

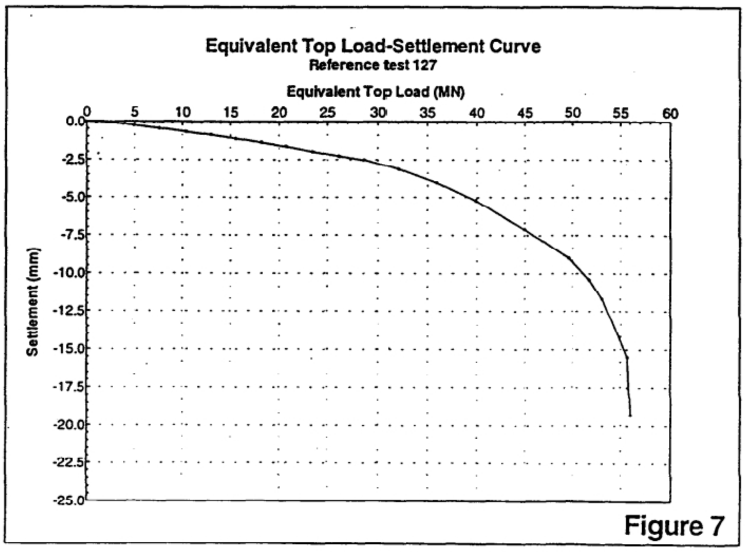


Figure 7

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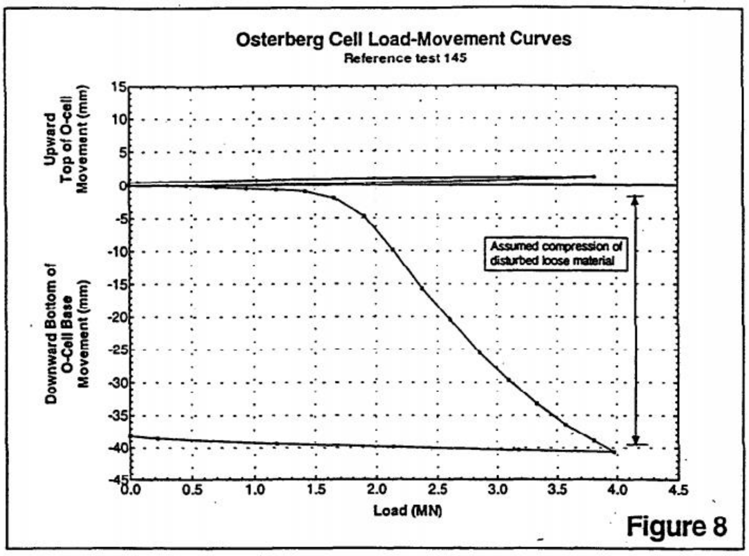


Figure 8

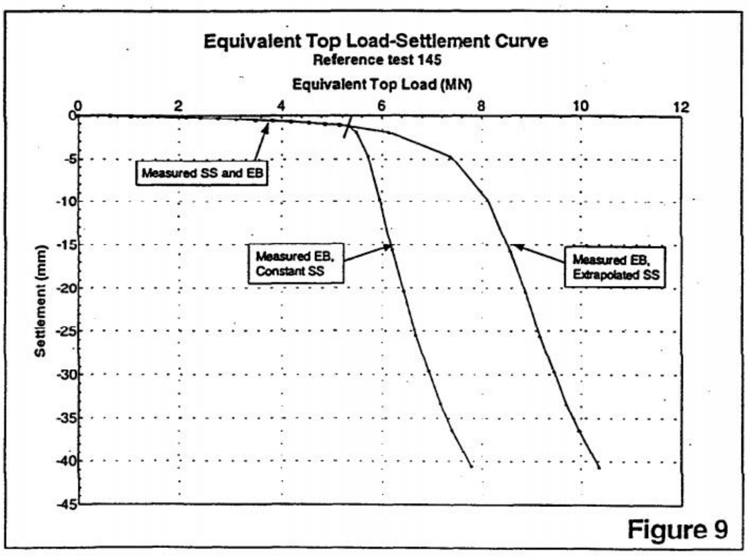
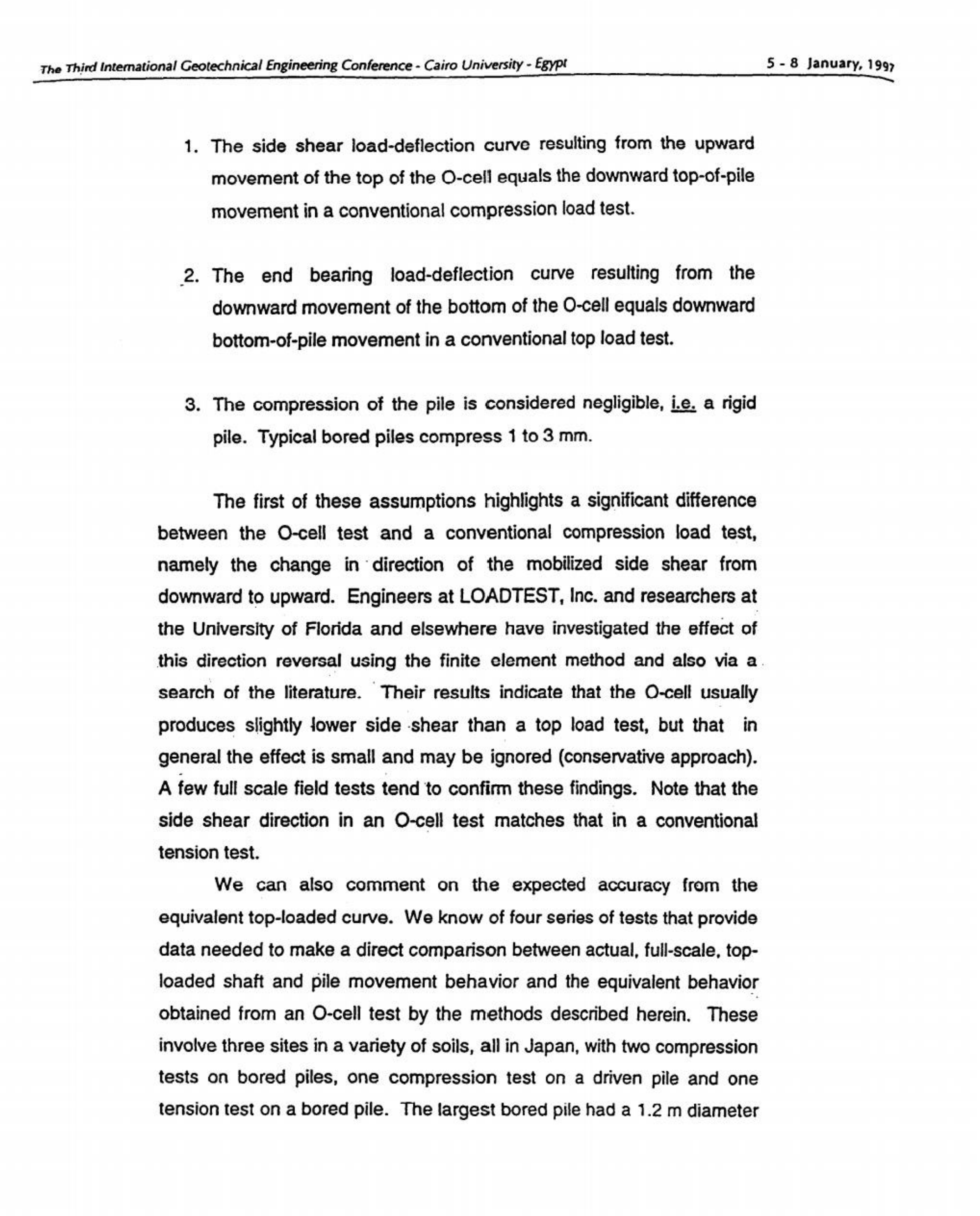


Figure 9



1. The side shear load-deflection curve resulting from the upward movement of the top of the O-cell equals the downward top-of-pile movement in a conventional compression load test.

2. The end bearing load-deflection curve resulting from the downward movement of the bottom of the O-cell equals downward bottom-of-pile movement in a conventional top load test.

3. The compression of the pile is considered negligible, i.e. a rigid pile. Typical bored piles compress 1 to 3 mm.

The first of these assumptions highlights a significant difference between the O-cell test and a conventional compression load test, namely the change in direction of the mobilized side shear from downward to upward. Engineers at LOADTEST, Inc. and researchers at the University of Florida and elsewhere have investigated the effect of this direction reversal using the finite element method and also via a search of the literature. Their results indicate that the O-cell usually produces slightly lower side shear than a top load test, but that in general the effect is small and may be ignored (conservative approach). A few full scale field tests tend to confirm these findings. Note that the side shear direction in an O-cell test matches that in a conventional tension test.

We can also comment on the expected accuracy from the equivalent top-loaded curve. We know of four series of tests that provide data needed to make a direct comparison between actual, full-scale, top-loaded shaft and pile movement behavior and the equivalent behavior obtained from an O-cell test by the methods described herein. These involve three sites in a variety of soils, all in Japan, with two compression tests on bored piles, one compression test on a driven pile and one tension test on a bored pile. The largest bored pile had a 1.2 m diameter and 37 m length. The driven pile had a 1-m increment modular construction and a 9 m length. Kisida et. al. (1992) and Ogura et. al. (1995) detail the aforementioned tests and the results therefrom.

We compared the predicted equivalent and measured movement behavior at three top movements in each of the above four comparisons, ranging from 6 to 40 mm movement depending on the data available. The (equiv./meas.) ratios averaged 1.03 in the 12 comparisons with a coefficient of variation 9.4%. We believe that these available comparisons help support the practical validity of the equivalent top load method described herein.

7. Observations from the O-cell Test Data

A review of the load test results from LOADTEST, Inc. files indicates that, in most cases, the measured capacity of the test shaft exceeds the designer's estimated ultimate capacity. Ironically, the ratio of measured to estimated capacity (M/E) tends to increase as the strength of the supporting strata improves. Figure 10 provides a summary of the M/E ratio data from 25 projects where we have information regarding the engineer's estimated capacities. Tables 7.1, 7.2 and 7.3 provide more detail about some of these projects in soils, intermediate materials and hard rocks, respectively.

We based the horizontal positioning on the graph within the material classifications shown on a subjective assessment of material characteristics. The data points with an upward arrow indicate tests in which neither component reached an ultimate capacity and, therefore, the test would plot at some unknown higher M/E ratio had the O-cell had enough capacity to reach an ultimate. (Note also that most of the M/E ratios would be somewhat higher than shown since the O-cell test usually determines the ultimate capacity of only one component.)

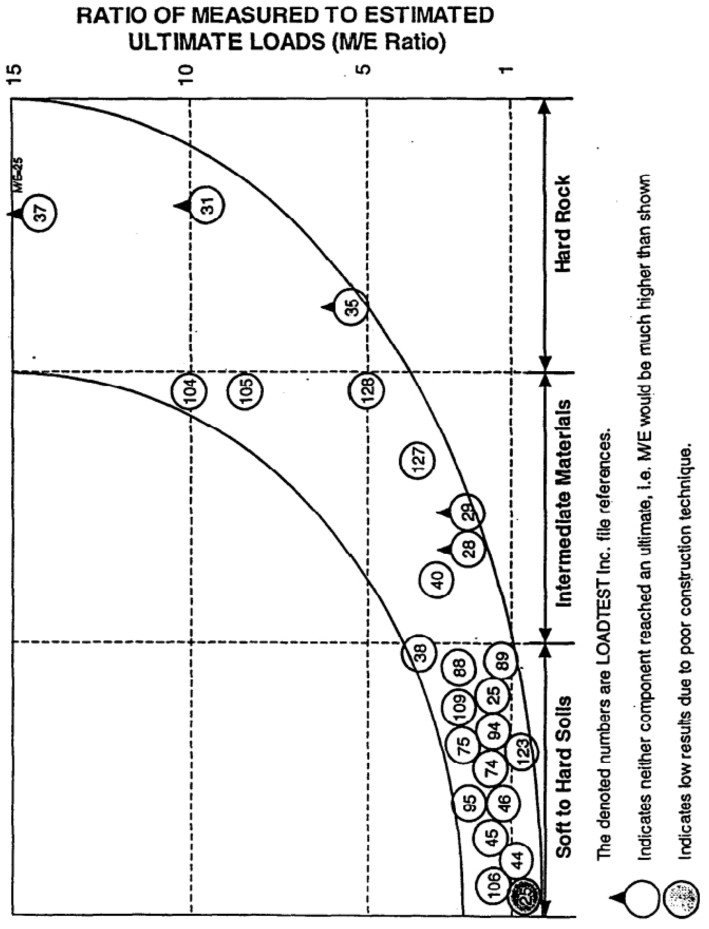

RATIO OF MEASURED TO ESTIMATED
ULTIMATE LOADS (M/E Ratio)
15
10
5
1
M/E=25
37
31
35
104
105
128
127
29
28
40
38
88
89
109
25
75
94
123
74
95
46
45
44
106
125
Hard Rock
Intermediate Materials
Soft to Hard Soils
The denoted numbers are LOADTEST Inc. file references.
Indicates neither component reached an ultimate, i.e. M/E would be much higher than shown
Indicates low results due to poor construction technique.

Figure 10

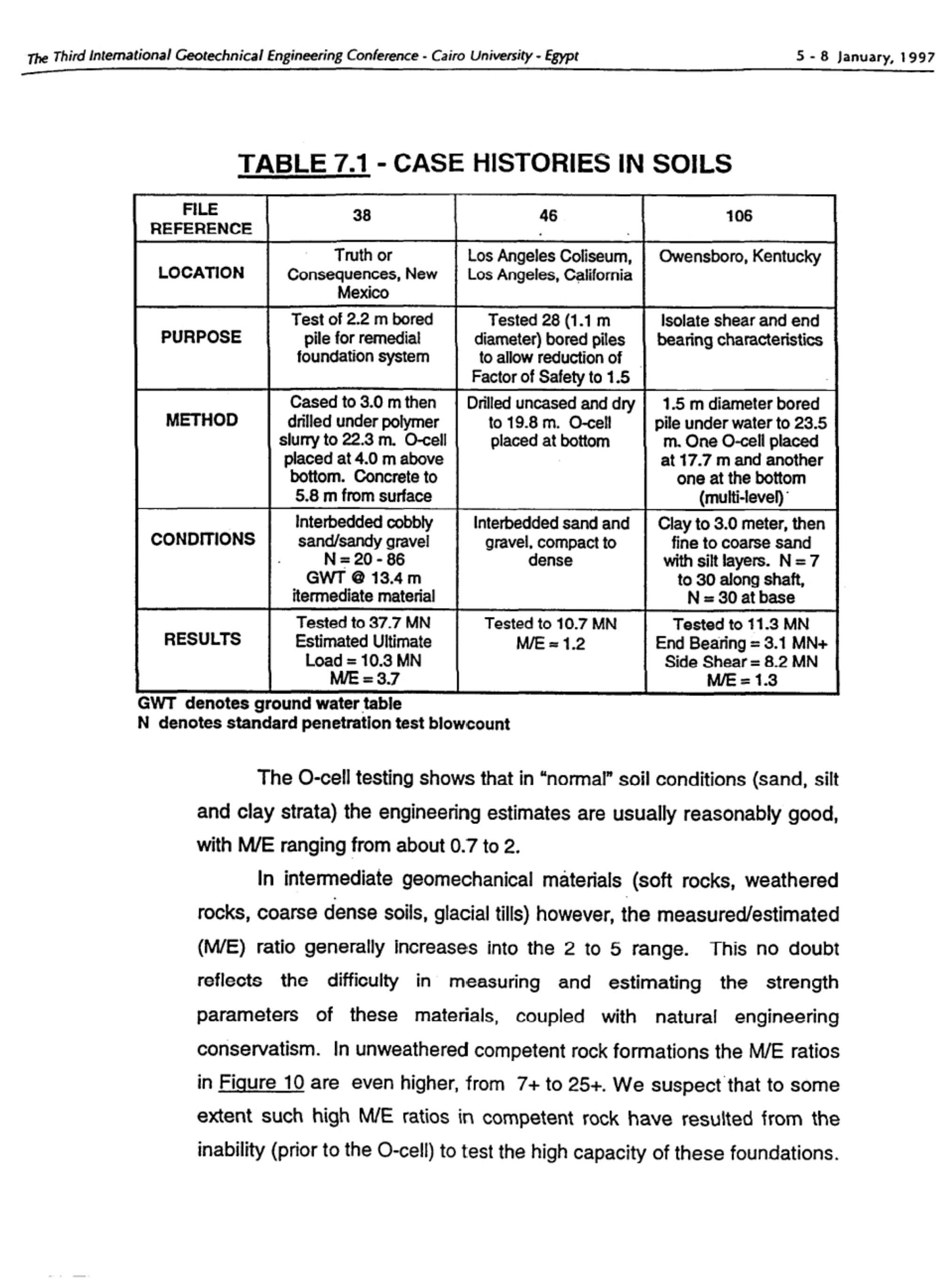


TABLE 7.1 - CASE HISTORIES IN SOILS

FILE REFERENCE	38	46	106
LOCATION	Truth or Consequences, New Mexico	Los Angeles Coliseum, Los Angeles, California	Owensboro, Kentucky
PURPOSE	Test of 2.2 m bored pile for remedial foundation system	Tested 28 (1.1 m diameter) bored piles to allow reduction of Factor of Safety to 1.5	Isolate shear and end bearing characteristics
METHOD	Cased to 3.0 m then drilled under polymer slurry to 22.3 m. O-cell placed at 4.0 m above bottom. Concrete to 5.8 m from surface	Drilled uncased and dry to 19.8 m. O-cell placed at bottom	1.5 m diameter bored pile under water to 23.5 m. One O-cell placed at 17.7 m and another one at the bottom (multi-level)
CONDITIONS	Interbedded cobbly sand/sandy gravel N = 20 - 86 GWT @ 13.4 m itermediate material	Interbedded sand and gravel, compact to dense	Clay to 3.0 meter, then fine to coarse sand with silt layers. N = 7 to 30 along shaft, N = 30 at base
RESULTS	Tested to 37.7 MN Estimated Ultimate Load = 10.3 MN M/E = 3.7	Tested to 10.7 MN M/E = 1.2	Tested to 11.3 MN End Bearing = 3.1 MN+ Side Shear = 8.2 MN M/E = 1.3

GWT denotes ground water table
N denotes standard penetration test blowcount

The O-cell testing shows that in "normal" soil conditions (sand, silt and clay strata) the engineering estimates are usually reasonably good, with M/E ranging from about 0.7 to 2.

In intermediate geomechanical materials (soft rocks, weathered rocks, coarse dense soils, glacial tills) however, the measured/estimated (M/E) ratio generally increases into the 2 to 5 range. This no doubt reflects the difficulty in measuring and estimating the strength parameters of these materials, coupled with natural engineering conservatism. In unweathered competent rock formations the M/E ratios in Figure 10 are even higher, from 7+ to 25+. We suspect that to some extent such high M/E ratios in competent rock have resulted from the inability (prior to the O-cell) to test the high capacity of these foundations.

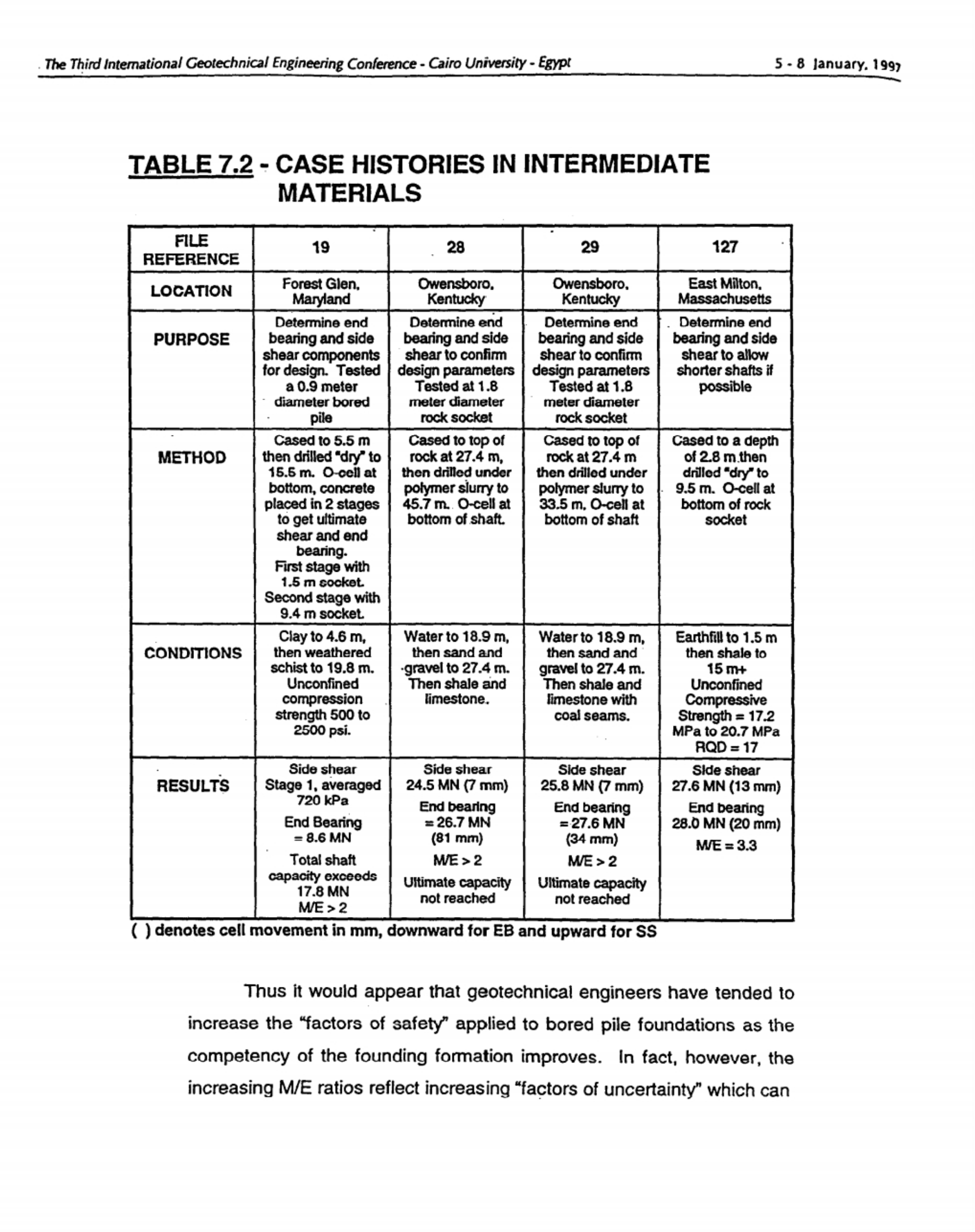


TABLE 7.2 - CASE HISTORIES IN INTERMEDIATE MATERIALS

FILE REFERENCE	19	28	29	127
LOCATION	Forest Glen, Maryland	Owensboro, Kentucky	Owensboro, Kentucky	East Milton, Massachusetts
PURPOSE	Determine end bearing and side shear components for design. Tested a 0.9 meter diameter bored pile	Determine end bearing and side shear to confirm design parameters Tested at 1.8 meter diameter rock socket	Determine end bearing and side shear to confirm design parameters Tested at 1.8 meter diameter rock socket	Determine end bearing and side shear to allow shorter shafts if possible
METHOD	Cased to 5.5 m then drilled "dry" to 15.5 m. O-cell at bottom, concrete placed in 2 stages to get ultimate shear and end bearing. First stage with 1.5 m socket. Second stage with 9.4 m socket.	Cased to top of rock at 27.4 m, then drilled under polymer slurry to 45.7 m. O-cell at bottom of shaft.	Cased to top of rock at 27.4 m then drilled under polymer slurry to 33.5 m. O-cell at bottom of shaft	Cased to a depth of 2.8 m then drilled "dry" to 9.5 m. O-cell at bottom of rock socket
CONDITIONS	Clay to 4.6 m, then weathered schist to 19.8 m. Unconfined compression strength 500 to 2500 psi.	Water to 18.9 m, then sand and gravel to 27.4 m. Then shale and limestone.	Water to 18.9 m, then sand and gravel to 27.4 m. Then shale and limestone with coal seams.	Earthfill to 1.5 m then shale to 15 m+ Unconfined Compressive Strength = 17.2 MPa to 20.7 MPa RQD = 17
RESULTS	Side shear Stage 1, averaged 720 kPa End Bearing = 8.6 MN Total shaft capacity exceeds 17.8 MN M/E > 2	Side shear 24.5 MN (7 mm) End bearing = 26.7 MN (81 mm) M/E > 2 Ultimate capacity not reached	Side shear 25.8 MN (7 mm) End bearing = 27.6 MN (34 mm) M/E > 2 Ultimate capacity not reached	Side shear 27.6 MN (13 mm) End bearing 28.0 MN (20 mm) M/E = 3.3

( ) denotes cell movement in mm, downward for EB and upward for SS

Thus it would appear that geotechnical engineers have tended to increase the "factors of safety" applied to bored pile foundations as the competency of the founding formation improves. In fact, however, the increasing M/E ratios reflect increasing "factors of uncertainty" which can

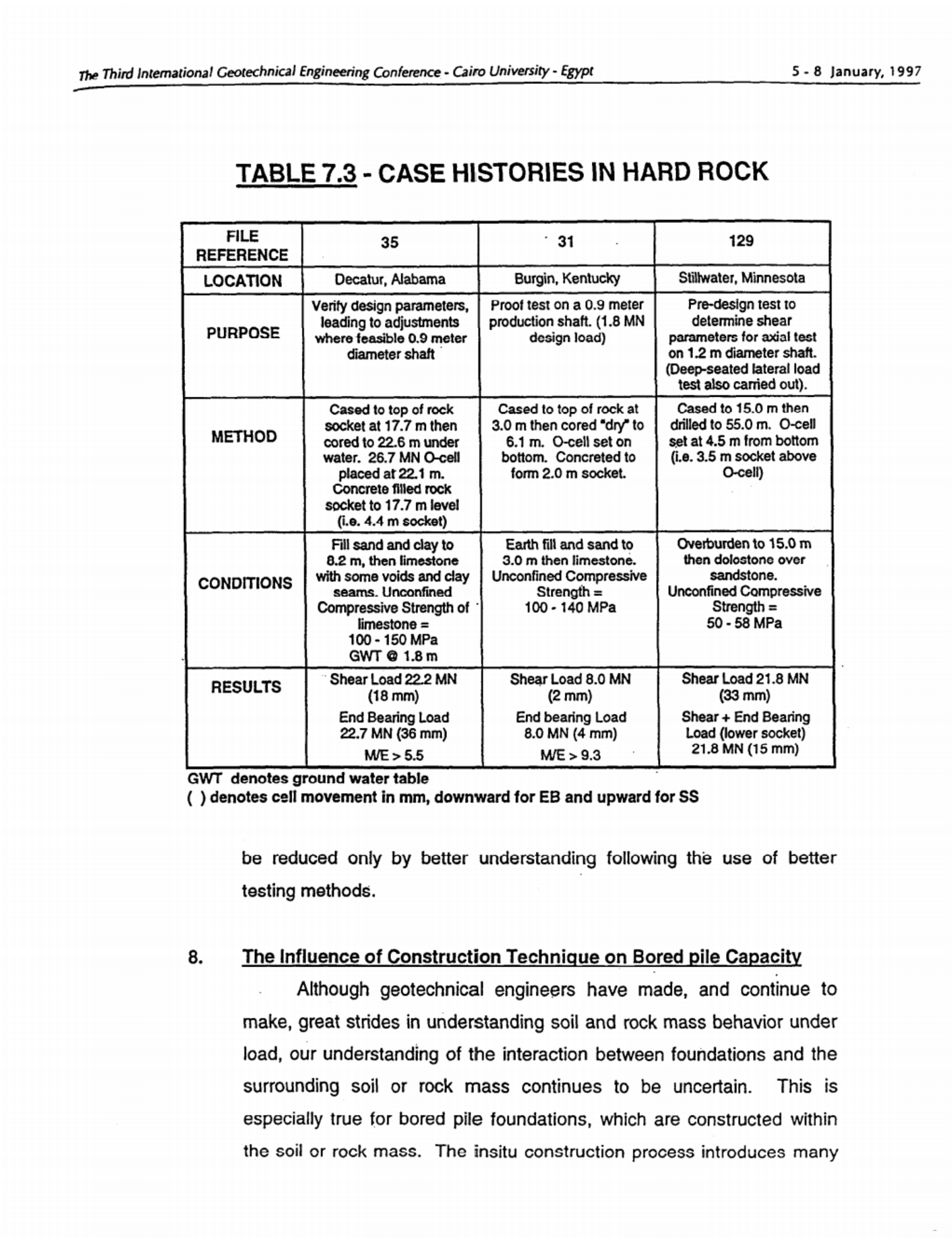


TABLE 7.3 - CASE HISTORIES IN HARD ROCK

FILE REFERENCE	35	31	129
LOCATION	Decatur, Alabama	Burgin, Kentucky	Stillwater, Minnesota
PURPOSE	Verify design parameters, leading to adjustments where feasible 0.9 meter diameter shaft	Proof test on a 0.9 meter production shaft. (1.8 MN design load)	Pre-design test to determine shear parameters for axial test on 1.2 m diameter shaft. (Deep-seated lateral load test also carried out).
METHOD	Cased to top of rock socket at 17.7 m then cored to 22.6 m under water. 26.7 MN O-cell placed at 22.1 m. Concrete filled rock socket to 17.7 m level (i.e. 4.4 m socket)	Cased to top of rock at 3.0 m then cored "dry" to 6.1 m. O-cell set on bottom. Concreted to form 2.0 m socket.	Cased to 15.0 m then drilled to 55.0 m. O-cell set at 4.5 m from bottom (i.e. 3.5 m socket above O-cell)
CONDITIONS	Fill sand and clay to 8.2 m, then limestone with some voids and clay seams. Unconfined Compressive Strength of limestone = 100 - 150 MPa GWT @ 1.8 m	Earth fill and sand to 3.0 m then limestone. Unconfined Compressive Strength = 100 - 140 MPa	Overburden to 15.0 m then dolostone over sandstone. Unconfined Compressive Strength = 50 - 58 MPa
RESULTS	Shear Load 22.2 MN (18 mm) End Bearing Load 22.7 MN (36 mm) M/E > 5.5	Shear Load 8.0 MN (2 mm) End bearing Load 8.0 MN (4 mm) M/E > 9.3	Shear Load 21.8 MN (33 mm) Shear + End Bearing Load (lower socket) 21.8 MN (15 mm)

GWT denotes ground water table
( ) denotes cell movement in mm, downward for EB and upward for SS

be reduced only by better understanding following the use of better testing methods.

8. The Influence of Construction Technique on Bored pile Capacity

Although geotechnical engineers have made, and continue to make, great strides in understanding soil and rock mass behavior under load, our understanding of the interaction between foundations and the surrounding soil or rock mass continues to be uncertain. This is especially true for bored pile foundations, which are constructed within the soil or rock mass. The insitu construction process introduces many

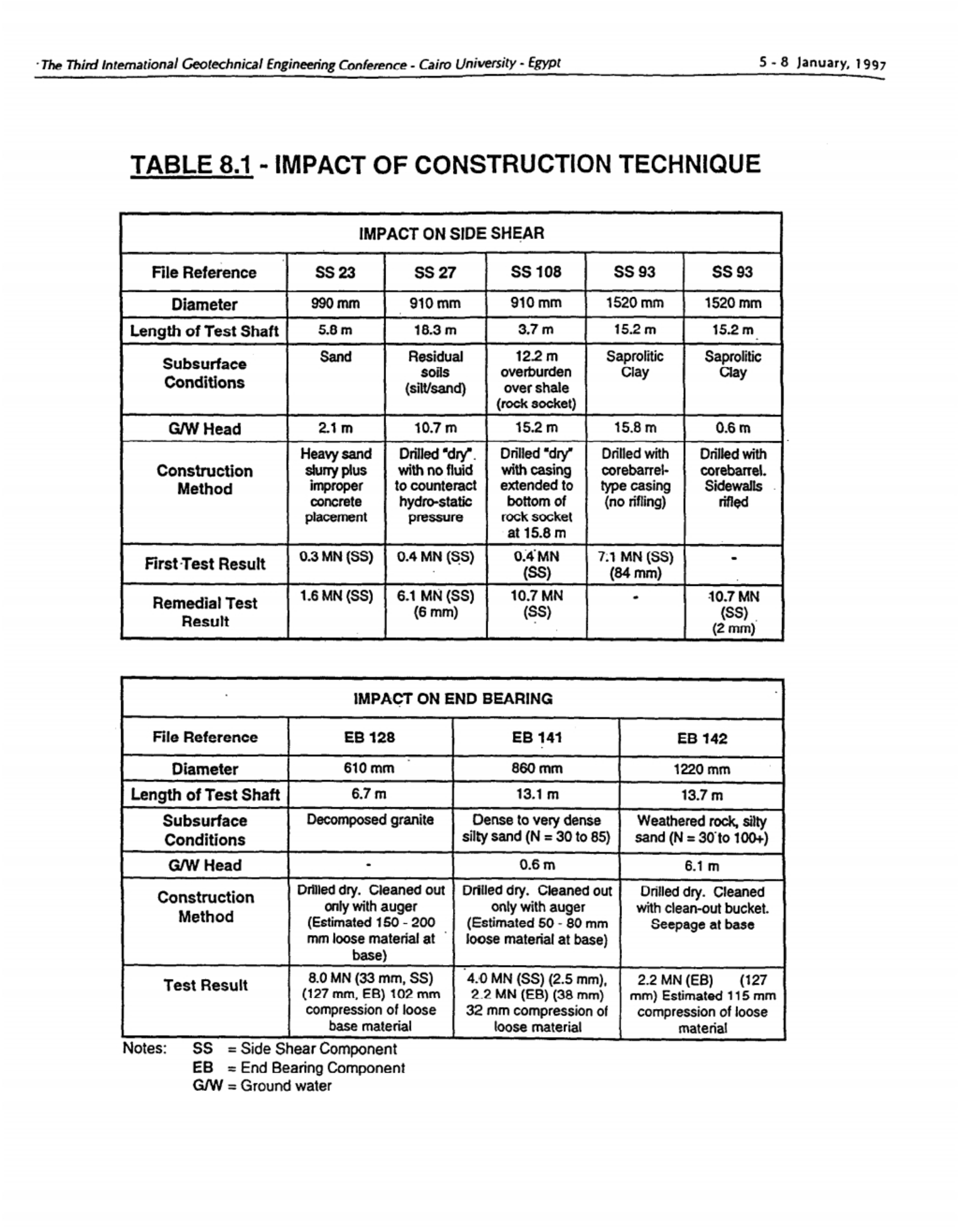


TABLE 8.1 - IMPACT OF CONSTRUCTION TECHNIQUE

IMPACT ON SIDE SHEAR

File Reference	SS 23	SS 27	SS 108	SS 93	SS 93
Diameter	990 mm	910 mm	910 mm	1520 mm	1520 mm
Length of Test Shaft	5.8 m	18.3 m	3.7 m	15.2 m	15.2 m
Subsurface Conditions	Sand	Residual soils (silt/sand)	12.2 m overburden over shale (rock socket)	Saprolitic Clay	Saprolitic Clay
G/W Head	2.1 m	10.7 m	15.2 m	15.8 m	0.6 m
Construction Method	Heavy sand slurry plus improper concrete placement	Drilled "dry" with no fluid to counteract hydro-static pressure	Drilled "dry" with casing extended to bottom of rock socket at 15.8 m	Drilled with corebarrel-type casing (no rifling)	Drilled with corebarrel. Sidewalls rifled
First Test Result	0.3 MN (SS)	0.4 MN (SS)	0.4 MN (SS)	7.1 MN (SS) (84 mm)	-
Remedial Test Result	1.6 MN (SS)	6.1 MN (SS) (6 mm)	10.7 MN (SS)	-	10.7 MN (SS) (2 mm)

IMPACT ON END BEARING

File Reference	EB 128	EB 141	EB 142
Diameter	610 mm	860 mm	1220 mm
Length of Test Shaft	6.7 m	13.1 m	13.7 m
Subsurface Conditions	Decomposed granite	Dense to very dense silty sand (N = 30 to 85)	Weathered rock, silty sand (N = 30 to 100+)
G/W Head	-	0.6 m	6.1 m
Construction Method	Drilled dry. Cleaned out only with auger (Estimated 150 - 200 mm loose material at base)	Drilled dry. Cleaned out only with auger (Estimated 50 - 80 mm loose material at base)	Drilled dry. Cleaned with clean-out bucket. Seepage at base
Test Result	8.0 MN (33 mm, SS) (127 mm, EB) 102 mm compression of loose base material	4.0 MN (SS) (2.5 mm), 2.2 MN (EB) (38 mm) 32 mm compression of loose material	2.2 MN (EB) (127 mm) Estimated 115 mm compression of loose material

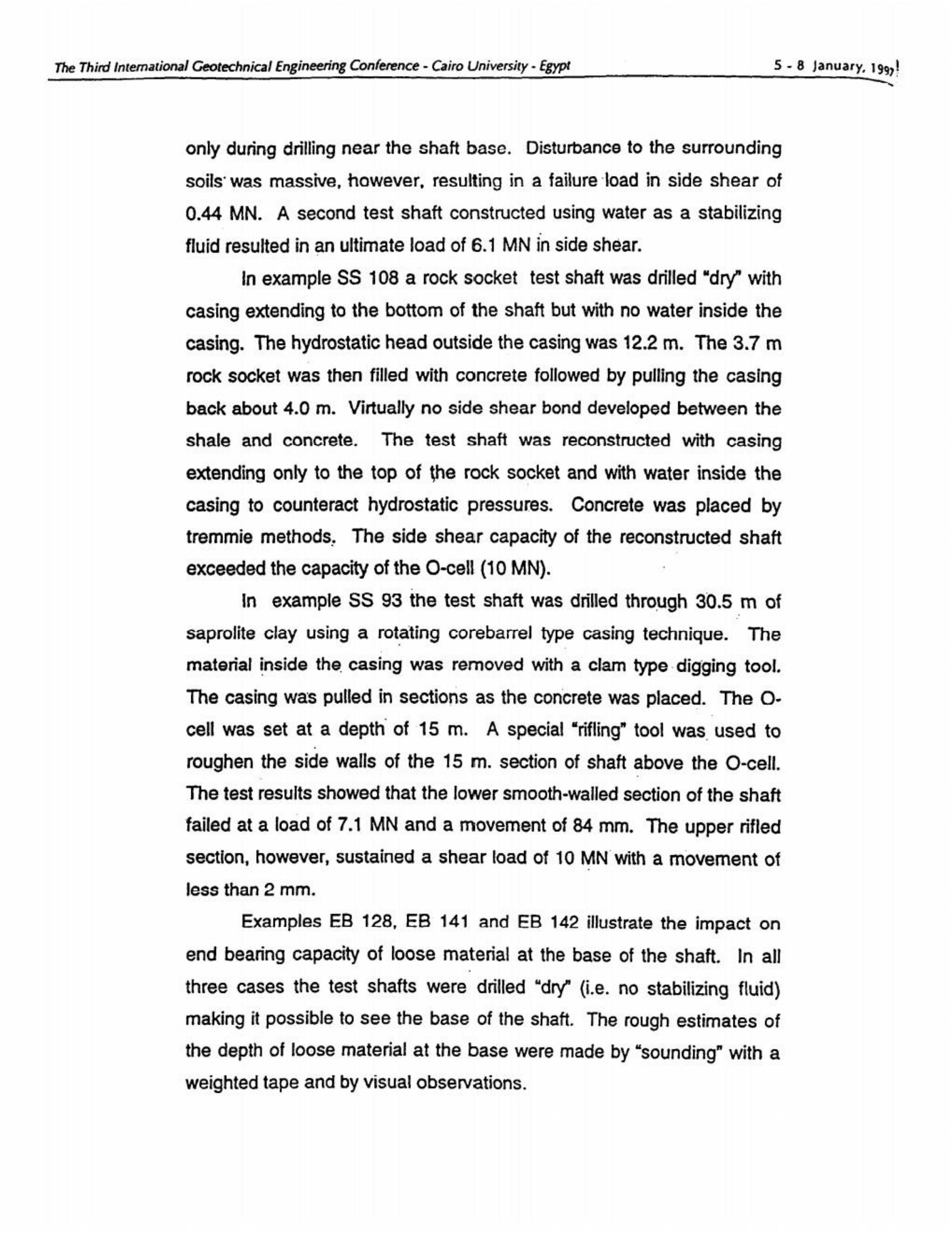
Notes:
SS = Side Shear Component
EB = End Bearing Component
G/W = Ground water

disturbing forces, and sometimes materials, which can have a profound effect on the subsequent behavior of the bored pile under load. In some cases the impact of the construction process can reduce actual bored pile capacities to 5% to 50% of the capacity achieved with better construction methods. Table 8.1 provides examples.

One of the characteristics of the O-cell test method is that it readily provides evidence of any abnormality related either to side shear or to end bearing capacity. This is an important distinction as compared to top load testing methods. A top load test may indicate apparently reasonable test capacity when, in fact, either the side shear component or the end bearing component could be seriously compromised by construction technique. The O-cell test by contrast relies on, and measures, both end bearing and side shear capacities and it is soon obvious if one of them is deficient. The examples in Table 8.1 illustrate how the O-cell test method has provided the comparative data we need to help our understanding of the impact of construction technique on bored pile capacity.

In example SS 23 the bored pile was constructed by "thinning" the soil with water and bentonite as the shaft was excavated. The drilling auger was used to churn the sand-water-bentonite mixture. Concrete was placed by lowering concrete through the "thinned" soil slurry using a cleanout bucket. The process resulted in highly disturbed soils both along the shaft side walls and at the shaft base. The construction procedure was changed to lower the sand content in the slurry to about 8% and the concrete was placed by tremmie (pumped) methods. The testing showed that the side shear increased from 15 kPa to 70 kPa as a result of the improved construction procedure.

In example SS 27 the contractor attempted to drill the shaft "dry," with no slurry to counteract hydrostatic pressure from groundwater. The residual soils were impermeable enough that seepage became evident



only during drilling near the shaft base. Disturbance to the surrounding soils was massive, however, resulting in a failure load in side shear of 0.44 MN. A second test shaft constructed using water as a stabilizing fluid resulted in an ultimate load of 6.1 MN in side shear.

In example SS 108 a rock socket test shaft was drilled "dry" with casing extending to the bottom of the shaft but with no water inside the casing. The hydrostatic head outside the casing was 12.2 m. The 3.7 m rock socket was then filled with concrete followed by pulling the casing back about 4.0 m. Virtually no side shear bond developed between the shale and concrete. The test shaft was reconstructed with casing extending only to the top of the rock socket and with water inside the casing to counteract hydrostatic pressures. Concrete was placed by tremmie methods. The side shear capacity of the reconstructed shaft exceeded the capacity of the O-cell (10 MN).

In example SS 93 the test shaft was drilled through 30.5 m of saprolite clay using a rotating corebarrel type casing technique. The material inside the casing was removed with a clam type digging tool. The casing was pulled in sections as the concrete was placed. The O-cell was set at a depth of 15 m. A special "rifling" tool was used to roughen the side walls of the 15 m. section of shaft above the O-cell. The test results showed that the lower smooth-walled section of the shaft failed at a load of 7.1 MN and a movement of 84 mm. The upper rifled section, however, sustained a shear load of 10 MN with a movement of less than 2 mm.

Examples EB 128, EB 141 and EB 142 illustrate the impact on end bearing capacity of loose material at the base of the shaft. In all three cases the test shafts were drilled "dry" (i.e. no stabilizing fluid) making it possible to see the base of the shaft. The rough estimates of the depth of loose material at the base were made by "sounding" with a weighted tape and by visual observations.

Figure 11 shows a typical end bearing load/movement curve from EB 128. The testing shows that for all practical purposes the end bearing capacity was lost (i.e. only 0.25 MN of end bearing at a movement of 25 mm). It should be noted that in all of these cases a typical top load test would not have revealed a significant problem with the test shaft capacity since the side shear capacity would have masked the end bearing deficiency.

Such experiences lead one to reflect on the potential bottom-condition problems wherein water or drilling mud prevents a simple visual inspection. As we have often seen when we inspect such shaft bottoms with a special video camera system designed for this purpose, considerable effort is often required to provide a "clean" bottom under those conditions. These experiences also reinforce the importance of load testing to determine the effect of construction technique as well as to assess side shear and end bearing parameters.

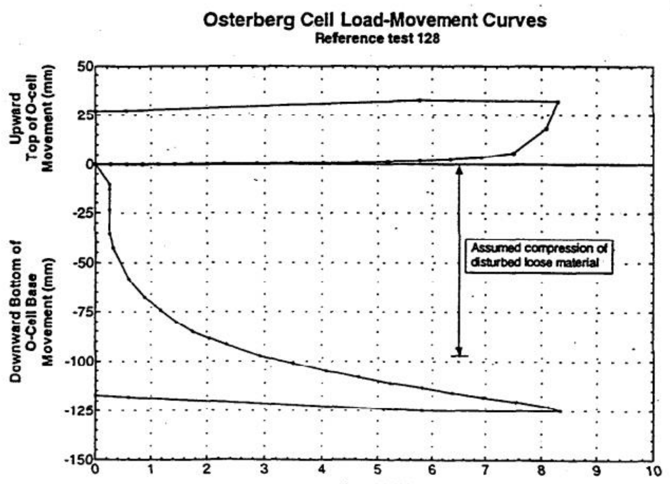
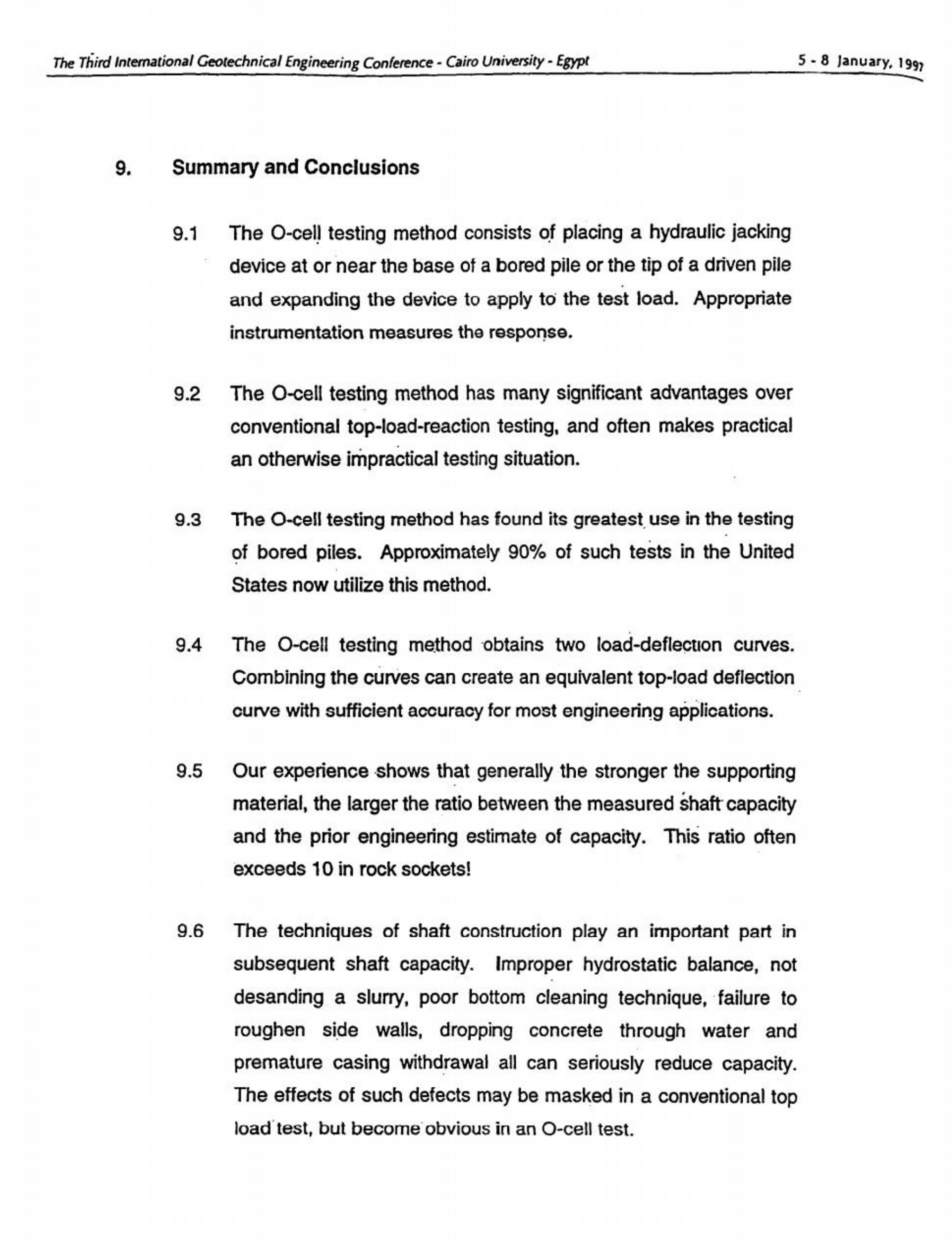


Figure 11



9. Summary and Conclusions

9.1 The O-cell testing method consists of placing a hydraulic jacking device at or near the base of a bored pile or the tip of a driven pile and expanding the device to apply to the test load. Appropriate instrumentation measures the response.

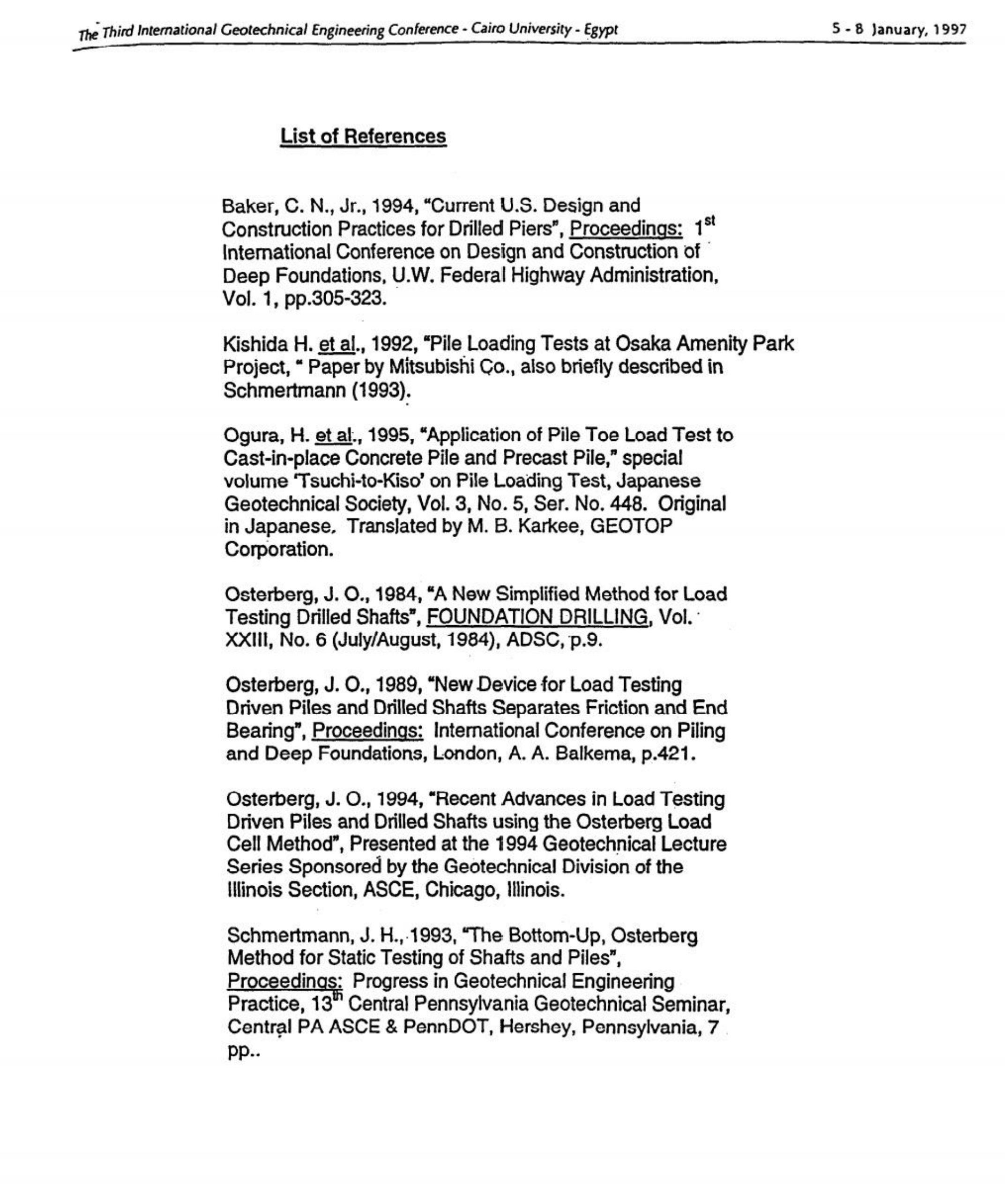
9.2 The O-cell testing method has many significant advantages over conventional top-load-reaction testing, and often makes practical an otherwise impractical testing situation.

9.3 The O-cell testing method has found its greatest use in the testing of bored piles. Approximately 90% of such tests in the United States now utilize this method.

9.4 The O-cell testing method obtains two load-deflection curves. Combining the curves can create an equivalent top-load deflection curve with sufficient accuracy for most engineering applications.

9.5 Our experience shows that generally the stronger the supporting material, the larger the ratio between the measured shaft capacity and the prior engineering estimate of capacity. This ratio often exceeds 10 in rock sockets!

9.6 The techniques of shaft construction play an important part in subsequent shaft capacity. Improper hydrostatic balance, not desanding a slurry, poor bottom cleaning technique, failure to roughen side walls, dropping concrete through water and premature casing withdrawal all can seriously reduce capacity. The effects of such defects may be masked in a conventional top load test, but become obvious in an O-cell test.



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