Bi-Directional Static Load Testing of Driven Piles

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Loadtest
Bi-Directional Osterberg Cell Testing

- Specialized jack in pile uses bearing to mobilize side shear
- Developed by Dr. Jorj Osterberg and AEFC
- LOADTEST Inc. founded 1991 (purchased by Fugro in 2008)
- First “O-cell” tests on driven steel pipe piles 1987
- >2000 O-cell tests to date, mostly drilled shafts (300+/yr)
- ~30 driven piles since 1987 (12”-66”, 52 tons – 1,480 tons)
Conventional Test

\[ P = F + Q \]

Osterberg Cell Test

\[ O = F = Q = \frac{P}{2} \]
\[ O = F_1 = (F_2 + Q) \]

Pile Provides Reaction
Driven Pile O-cell Installation

O-cell cast into or welded to pile before driving

30" PSC Pile, Morgan City, LA

O-cell grouted into pile after driving

66" Cylinder Pile, Harrison County, MS
O-cell Features

- Robust for installation
- Aligned with pile axis
- Special seal for eccentricity
- Water used for hydraulic fluid
- Rated at 10,000 psi
- Calibrated by AEFC (NIST Traceability)
- Linear & Repeatable
- Strain gauges also confirm load
O-cell Instrumentation

- O-cell Pressure monitored by gauge and transducer
- Pile Top Movement
- O-cell Expansion Transducers
- O-cell Top Telltales
- Pile Bottom Telltales
- Embedded Strain Gauges
- Embedded Pile Compression Transducers
O-cell Test Setup

- ASTM D1143 Quick Test (new standard coming)
- 20 Loads to failure
- 8 min load intervals (identify creep limit)
- All instruments monitored by datalogger
- Real-time load vs. deflection plot
- Reference beams replaced by electronic levels
## O-cell Sizes

<table>
<thead>
<tr>
<th>O-cell Size</th>
<th>Rated Capacity</th>
<th>Max. Test Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>6”</td>
<td>100 tons</td>
<td>200 tons</td>
</tr>
<tr>
<td>9”</td>
<td>225 tons</td>
<td>450 tons</td>
</tr>
<tr>
<td>13”</td>
<td>438 tons</td>
<td>875 tons</td>
</tr>
<tr>
<td>16”</td>
<td>700 tons</td>
<td>1400 tons</td>
</tr>
<tr>
<td>20”</td>
<td>1125 tons</td>
<td>2250 tons</td>
</tr>
<tr>
<td>24”</td>
<td>1550 tons</td>
<td>3100 tons</td>
</tr>
<tr>
<td>26”</td>
<td>1950 tons</td>
<td>3900 tons</td>
</tr>
<tr>
<td>34”</td>
<td>3000 tons</td>
<td>6000 tons</td>
</tr>
</tbody>
</table>

- Cells typically welded to load plates
- Cells can be grouped together
- 6” stroke standard, 9” stroke available
**Special Features of Driven Pile O-cells**

- AEFC welds plates to O-cell that fit pile form (or pile ID)
- O-cell welded shut for safe pile handling
- O-cell placed at pile bottom
- O-cell skirt / enclosure provided (if driven)
- Rebar anchors cell to pile
- Vent pipe to minimize disturbance at cell opening
- Instrumentation cables and hoses coiled at top of pile
Example: 18” Steel Pipe Piles, MA

**Saugus River Bridge**
- Delmag D62-22
- Refusal 10 blows /0.5”
- 142 tons O-cell Load
- 0.28 tsf Side Resistance Failure (0.3”)
- 80 tsf End Bearing (not failed)
- 284 tons Capacity

**Pines River Bridge**
- Delmag D36-13
- Refusal 10 blows /0.5”
- 215 tons O-cell Load
- 0.39 tsf Side Resistance Failure (0.3”)
- 122 tsf End Bearing (not failed)
- 430 tons Capacity
FL Research Pile Setup

- Five 18” PSC Piles
- PDA Tests
- Long-term, staged static tests (25)
- Osterberg Cell in tip
- Strain Gages
- Telltales
- Piezometers
- DMT Stress Cells
FL Research Pile Setup: O-cell
FL Research Pile Setup – Arithmetic Plot

- Aucilla, Dynamic Test
- Aucilla, Static Test

Pile Side Shear $Q_s$ (kN)

- Bullock et al. (1995) in FL 18” PSC, O-cell at bottom

Elapsed Time, $t$ (days)

1727 days

= 225 tons

60 min
15 min
1 min
Bullock et al. (1995) in FL 18” PSC, O-cell at bottom

Q_{S0} = 1021 kN (at t_0 = 1 day)

m_S = 293.4 kN

= 225 tons

EOID Capacity plotted at 1 min
**FL Research Pile Setup – Non-dimensional Plot**

- **Aucilla, Dynamic Test**
- **Aucilla, Static Test**

**Equation:**

\[ A = \left( \frac{m_S}{Q_{S0}} \right) = 0.30 \]

\[ R^2 = 0.99 \]

**Graph Notes:**

- **Pile Side Shear Ratio:** \( \left( \frac{Q_s}{Q_{s0}} \right) \)

- **Elapsed Time Ratio:** \( \left( \frac{t}{t_0} \right) \) with \( t_0 = 1 \) day

- **Data Points:**
  - 1 min
  - 15 min
  - 60 min

- **Percentage Changes:**
  - +30% in 1 day
  - +14% in 1-3d
  - +25% in 1-7d

- **Total Change:** +90% in 1 day (or 9X 1 min capacity)

- **Bullock et al. (1995) in FL 18” PSC, O-cell at bottom**

- **Plot Notes:**
  - \( \Sigma = +90\% \) in 1 day
  - About half of EOD-1d change
  - 1-28d +43% or
Example: Morgan City, LA - 30” PSC

- HPSI 2500, 300 bpf
- 30” PSC, 18” Void, 143 ft long
- Pile Setup Clay/Sand
- 950 ton O-cell

Max. O-cell Load 493 tons
Buoyant Pile Weight 29 tons

- 464 tons at 5 wks
- 416 tons at 3 wks
- 369 tons at 1wk
Example: Busan, Korea - 24” PHC

- Prestressed Spun High Strength Conc.
- 24” OD, 16” ID, 103 ft long, 46 ft sections
- Sand / Clay / Sand
- 875 ton O-cell, 7 Strain Levels, Grouted

Max. O-cell Load 472 (944 ton test)
Buoyant Pile Weight 16 tons
Max. Side Shear 456 tons
Unit Side Shear 0.14 to 1.98 tsf
Max. End Bearing 155 tsf
Example: Harrison County, MS - 66” Cylinder

- Conmaco 300, 128 bpf EOID
- 66” OD, 54” ID, 108 ft long
- Silt / Sand / Dense Sand
- 3000 ton O-cell, 4 Strain Levels

Max. O-cell Load 740 tons (1480 ton test)
Buoyant Pile Weight 114 tons
Max. Side Shear 626 tons
Unit Side Shear 0.23 to 4.10 tsf
Max. End Bearing 45 tsf
Efficient O-cell Test Applications

- End bearing $\approx$ side resistance (use ultimate!)
- Restricted site access (remote location, existing structures, environmentally sensitive, water)
- Prove capacity distribution (end bearing vs. side resistance, unit side resistance)
- Accelerated construction schedule
- Large test loads required
- Site safety restrictions (personnel & equipment)
- Repeated tests (setup)
- Multiple test piles (but only one test frame)
- Compare with total cost of conventional testing
O-cell Test Limitations

- Pile preselected for testing
- Maximum load limited by the weaker of the end bearing or side shear (add top load?)
- Top of pile not structurally tested
- Subtract buoyant weight of pile above O-cell to calculate side resistance
- Must construct equivalent top load movement curve
  - use the sum of measured behavior
  - use the sum of modeled behavior
  - use finite element or t-z approach
Typical O-cell Test Result

- Upward movement from O-cell as measured
- Maximum O-cell load applied
- Downward movement from O-cell as measured

2,700 tons

Applied Load (MN) (1 MN = 112.4 tons)
Equivalent Top-Load Curve

- **Load-Movement from O-cell as measured upwards (minus buoyant weight) and as expected to behave downwards**
- **Downward movement from O-cell as measured**
- **Sum of the behaviours measured above and below O-cell**
- **Extrapolated behaviour above O-cell**

**Graph Details**
- **Y-axis:** Pile head displacement (mm)
- **X-axis:** Net Applied Load (MN)
- The graph shows the relationship between pile head displacement and net applied load.
Equiv. Top-Load + Elastic Shortening

- Measured behaviour curve
- Modified to include Additional Elastic Compression

Graph showing the relationship between Top Settlement (millimeters) and Net Load (MN).
• **RIM-cell** pressurizes pile cross-section
• Full-scale static bi-directional load test
• Install a **RIM**-cell in any pile
• Economical testing
• QA/QC device eliminates uncertainty
• End-bearing engaged during test, stiffens shaft response under load

**60” RIM-cell**
Cross-section of a **RIM**-cell installed at the shaft toe.
The **RIM**-cell confines the fluid pressure, creating a hydraulic cylinder at the shaft toe capable of applying high static loads.
Fluid grout is pumped through the hydraulic hoses creating a fracture across the shaft, pressurized within the RIM-cell.
As the internal grout sets, more grout is pumped into external pipes to fill the annular fracture around the RIM-cell.
USING THE RIM-CELL

• **PROOF TEST**
  • Install in every pile
  • Load shafts to design load or higher (2000 – 5000 psi)
  • Eliminate uncertainty of site variability
  • Use higher LRFD factors
  • Detect / remediate a “soft toe”

• **POST-STRESSING**
  • Consolidate loose material at shaft toe
  • Engage end bearing without losing side shear
  • Limit settlement at service load
RIM-CELL ASSEMBLY

Designed for drilled shaft construction. RIM-cell fits inside reinforcing cage. Hydraulic hoses and instrumentation pipe installed on the cage. Add strain gages, etc. to isolate and analyze different soil strata.

60” RIM-cell

24” RIM-cell installed with 8 levels of strain gages

RIM-cell welded to frame below O-cell assembly for a multi-level test shaft.
After shaft excavated and approved, hang cage with RIM-cell at the desired elevation. Large center opening allows tremie pipe to pass during concrete placement. Low cross-sectional area does not inhibit concrete flow or trap loose materials.
Perform test after concrete obtains strength. Cement grout is mixed and pumped through the hydraulic hoses into the RIM-cell. Measured pressure is converted to load using calibration factor of the RIM-cell. Load is increased to 1.2 to 1.5 times design load. Shaft movement is measured and recorded. Grout will set up to restore integrity to the shaft.
The **RIM-cell** report similar to O-cell test report. Load-Displacement plot generated in real time during test. Electronic preliminary results available the same day as the test.

![Schematic section of RIM-cell shaft](image1.png)

![Equivalent Top Load Plot](image2.png)
RIM-CELL LIMITATIONS

- Internal friction unknown (but small)
- Preselect shaft (install in every shaft, test as required)
- Reduced pressure vs. O-cell (but large area)
- Typically will not test to failure
- Grouting required to restore shaft integrity
- Maximum load limited by the weaker of the end bearing or side shear (add top load?)
- Top of pile not structurally tested
MISSOURI RESEARCH PROJECT

- 24” bi-directional test piles on two different sites
- Two piles on each site were tested using RIM-cells
- 24” RIM-cells in 36” piles
- 20-30 feet deep shafts in unweathered and weathered shale
- Side by side comparison to O-cell tests
Similar piles on same site. O-cell test (red) taken to ultimate capacity. RIM-cell test (blue) taken to design load. Plots show similar deformations at design load.
## RIM-CELL Tests to Date

<table>
<thead>
<tr>
<th>RIM-cell Size</th>
<th>Shaft Diameter</th>
<th>Max Pressure</th>
<th>Max Cell Load</th>
<th>Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>14&quot;</td>
<td>24&quot;</td>
<td>2500 psi</td>
<td>350 kips</td>
<td>Side Shear Failure</td>
</tr>
<tr>
<td>14&quot;</td>
<td>24&quot;</td>
<td>1780 psi</td>
<td>250 kips</td>
<td>End Bearing Failure</td>
</tr>
<tr>
<td>20&quot;</td>
<td>30&quot;</td>
<td>1530 psi</td>
<td>450 kips</td>
<td>Side Shear Failure</td>
</tr>
<tr>
<td>20&quot;</td>
<td>30&quot;</td>
<td>1360 psi</td>
<td>400 kips</td>
<td>Side Shear Failure</td>
</tr>
<tr>
<td>24&quot;</td>
<td>36&quot;</td>
<td>2560 psi</td>
<td>1100 kips</td>
<td>RIM-cell Capacity Maxed Out</td>
</tr>
<tr>
<td>24&quot;</td>
<td>36&quot;</td>
<td>1980 psi</td>
<td>850 kips</td>
<td>RIM-cell Capacity Maxed Out</td>
</tr>
<tr>
<td>24&quot;</td>
<td>36&quot;</td>
<td>640 psi</td>
<td>275 kips</td>
<td>End Bearing Failure</td>
</tr>
<tr>
<td>24&quot;</td>
<td>36&quot;</td>
<td>1170 psi</td>
<td>500 kips</td>
<td>End Bearing Failure</td>
</tr>
<tr>
<td>24&quot;</td>
<td>30&quot;</td>
<td>940 psi</td>
<td>400 kips</td>
<td>Test stopped at 1&quot; Expansion</td>
</tr>
<tr>
<td>36&quot;</td>
<td>54&quot;</td>
<td>475 psi</td>
<td>450 kips</td>
<td>Side Shear Failure</td>
</tr>
<tr>
<td>36&quot;</td>
<td>(76&quot;rock socket)</td>
<td>4950 psi</td>
<td>13,000 kips</td>
<td>Test stopped at 1/2&quot; Expansion</td>
</tr>
<tr>
<td>60&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Summary

- O-cell test proven for driven piles
- Compare overall cost and quality of test results for conventional top-down testing with O-cell testing
- RIM-CELL tests to verify production pile capacity (QA/QC)
- Coming Attractions:
  - New ASTM Standard
  - Bigger piles, higher loads
  - Mid-pile O-cell placement for spliced concrete piles
  - Mid-pile placement for steel pipe piles
Thank You

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