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# REPORT ON DRILLED SHAFT LOAD TESTING (OSTERBERG METHOD)

## Test Shaft #1 - 42nd Street / I-235 Overpass
## Des Moines, IA (LT-8756-1)

**Prepared for:** Longfellow Drilling, Inc.
RR 1 Box 123
Clearfield, IA 50840

**Attention:** Mr. Mike Kemery

**PROJECT NUMBER: LT-8756-1, April 24, 2002**


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LOADTEST

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DEEP FOUNDATION TESTING, EQUIPMENT & SERVICES • SPECIALIZING IN OSTERBERG CELL (O-cell™) TECHNOLOGY

April 24, 2002

**Longfellow Drilling, Inc.**
**RR 1 Box 123**
**Clearfield, IA 50840**

Attention: Mr. Mike Kemery

**Data Report:** Test Shaft #1 - 42nd Street / I-235 Overpass
**Location:** Des Moines, IA (LT-8756-1)

The enclosed report contains the data and analysis summary for the O-cell™ test performed on Test Shaft #1 - 42nd Street / I-235 Overpass, on April 17, 2002. For your convenience, we have included an executive summary of the test results in addition to our standard detailed data report.

We would like to express our gratitude for the on-site and off-site assistance provided by your team and we look forward to working with you on future projects.

We trust that the information contained herein will suit your current project needs. If you have any questions or require further technical assistance, please do not hesitate to contact us at 800-368-1138.

Best Regards,

David J. Jakstis, B.S.C.E.
LOADTEST, Inc.

## EXECUTIVE SUMMARY

On April 17, 2002, we tested a 1219-mm* (48-inch) diameter production shaft constructed by Longfellow Drilling, Inc. Mr. David J. Jakstis and Mr. Michael D. Ahrens of LOADTEST, Inc. carried out the test. Longfellow Drilling, Inc. excavated and installed the 20.26-m (66.5-ft) deep shaft socketed in shale under polymer slurry on April 11th and April 12th, 2002. Sub-surface conditions at the test shaft location consist primarily of glacial clay underlain by shale. Representatives of the Iowa Department of Transportation and the Federal Highway Administration observed construction and testing of the shaft.

The maximum bi-directional load applied to the shaft was 4.79 MN (1,077 kips). At the maximum load, the displacements above and below the O-cell were 30.61 mm (1.205 inches) and 6.82 mm (0.269 inches), respectively. Average unit shear data calculated from strain gages included a maximum calculated net unit side shear of 216 kPa (4.5 ksf), occurring between the O-cell™ and strain gage level 2. We calculated a maximum applied end bearing pressure of 1926 kPa (40.2 ksf).

Using the procedures described in the report text and in Appendix C, we constructed an equivalent top load curve for the test shaft. For a top loading of 6.2 MN (1,391 kips), the adjusted test data indicate this shaft would settle approximately 6.3 mm (0.25 inches) of which 2.5 mm (0.10 inches) is estimated elastic compression.

### LIMITATIONS OF EXECUTIVE SUMMARY

We include this executive summary to provide a very brief presentation of some of the key elements of this O-cell™ test. It is by no means intended to be a comprehensive or stand-alone representation of the test results. The full text of the report and the attached appendices contain important information which the engineer can use to come to more informed conclusions about the data presented herein.

* Throughout this report, we use SI as primary units and English as secondary.

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## SITE CONDITIONS AND SHAFT CONSTRUCTION

**Site Sub-surface Conditions:** The sub-surface stratigraphy at the general location of the test shaft is reported to consist of glacial clay down to elevation +282.3 m (+926 ft). Below this strata, a layer of soft shale was encountered to elevation +277.3 m (+910 ft) underlain by firm shale to an undetermined depth. The generalized subsurface profile is included in Figure A and boring logs indicating conditions near the shaft are presented in Appendix E. More detailed geologic information can be obtained from the Iowa Department of Transportation.

**Test Shaft Construction:** Longfellow Drilling, Inc. excavated the production test shaft and performed the final cleanout on April 11, 2002 and finished concreting on April 12, 2002. We understand that the 1,220-mm (48-inch) test shaft was constructed to a tip elevation of +276.01 m (+905.6 ft), under polymer slurry. The shaft was started by excavating and screwing in a 1422-mm (56-inch) O.D. casing to stabilize near-surface soils. An auger was used for drilling the shaft. The bottom 4.88 m (16.0 ft) of the shaft was grooved (25-mm by 50-mm) (1-inch by 2-inch) at 0.3 m (1 ft) increments, followed by a wire brush tool. After cleaning the base with a bucket, the reinforcing cage with attached O-cell™ assembly was inserted into the excavation and temporarily suspended from the crane. Concrete was then delivered by pump through a 102-mm (4-inch) O.D. pipe into the base of the shaft until the top of the concrete reached an elevation of +296.27 meters (+972.0 feet). The contractor removed the 1422-mm (56-inch) O.D. casing immediately after concrete placement. No unusual problems occurred during construction of the shaft. Representatives of the Iowa Department of Transportation and the Federal Highway Administration observed construction of the shaft.

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## OSTERBERG CELL TESTING

**Shaft Instrumentation:** Test shaft instrumentation and assembly was carried out under the direction of Mr. David J. Jakstis of LOADTEST, Inc. on April 9, 2002. The loading assembly consisted of one 670-mm O-cell™ located 3.99 meters (13.1 feet) above the tip of shaft. The Osterberg cell was calibrated to 13.72 MN (3085 kips) and then welded closed prior to shipping by American Equipment and Fabricating Corporation. Calibrations of O-cell™ and instrumentation used for this test are included in Appendix B.

O-cell™ testing instrumentation included three Linear Vibrating Wire Displacement Transducers LVWDT) – (Geokon Model 4450 series) positioned between the lower and upper plates of the O-cell™ assembly to measure expansion (Appendix A, Page 2). Two telltale casings were attached to the reinforcing cage, diametrically opposed, extending between the top of the O-cell™ assembly and the top of concrete.

Strain gages were used to assess the side shear load transfer of the shaft above and below the Osterberg cell assembly. One level of two sister bar vibrating wire strain gages (Geokon Model 4911 Series) were installed, diametrically opposed, in the shaft below the base of the O-cell™ assembly and two levels of two were installed in the shaft above it. Details concerning the strain gage placement appear in Table B and Figure A. The strain gages were positioned as specified by the Iowa Department of Transportation.

Two lengths of steel pipe were also installed, extending from the top of the shaft to the top of the bottom plate, to vent the break in the shaft formed by the expansion of the O-cell™. The pipes were filled with water prior to the start of the test. The pipes also provide access for post-test grouting of the annular void surrounding the O-cell™ assembly as described in Appendix J.

**Test Arrangement:** Throughout the load test, key elements of shaft response were monitored using the equipment and instruments described herein. Shaft compression was measured using telltales monitored by Linear Voltage Displacement Transducers (LVDT) (RDP Series). Two LVDTs attached to a reference system were used to monitor the top of shaft movement (Appendix A, Page 1).

The reference system consisted of an 8.84-meter (29-foot) steel wide flange section supported on wooden wire spools. The supports were located approximately 2.5 shaft diameters from the center of the test shaft. The beam was shaded for the duration of the test. An automated digital survey level (Leica NA 3003) was used to monitor the reference beam for movement during testing from a distance of approximately 16.6 meters (54 feet) (Appendix F). A maximum upward movement of 0.51 mm (0.02 inches) was observed for the reference beam. The top of shaft movements have been corrected for movement of the reference system (Appendix A, Page 1).

Both Bourdon pressure gages and a vibrating wire pressure transducer were used to measure the pressure applied to the O-cell™ at each load interval. We used the Bourdon pressure gage for setting and maintaining loads and for data analysis. The transducer readings were used for real time plotting and as a check on the Bourdon gage. There was close agreement between the Bourdon gage and the pressure transducer.

**Data Acquisition:** All instrumentation were connected through a data logger (Campbell Scientific CR-10X), to a laptop computer, allowing data to be recorded and stored automatically at 30 second intervals and displayed in real time. A separate laptop computer time synchronized to the data logging system was used to acquire the Leica NA3003 data.

**Testing Procedures:** As with all of our tests, we begin by pressurizing the O-cell™ in order to break the tack welds that hold it closed (for handling and construction of the shaft) and to form the fracture plane in the concrete surrounding the base of the O-cell™. After the break occurs, we immediately release the pressure and then begin the loading procedure. Zero readings for all instrumentation are taken prior to the preliminary weld-breaking load-unload cycle, which in this case involved a maximum applied pressure of 5.17 MPa (750 psi) to the O-cell™.

The Osterberg cell load test was conducted as follows: We pressurized the 660-mm (26-inch) diameter O-cell™, with its base located 3.99 meters (13.1 feet) above the base of shaft to assess the combined end bearing and lower side shear below the O-cell™ and the upper side shear above. We pressurized the O-cell™ in six loading increments to 19.99 MPa (2,900 psi) resulting in a bi-directional gross O-cell™ load of 4.79 MN (1,077 kips). The loading was halted after load interval 1L-6 because the upper side shear was displacing rapidly upward. The O-cell™ was depressurized in three decrements. The O-cell™ was then repressurized in three loading increments to a bi-directional gross O-cell™ load of 3.32 MN (747 kips) at 2L-3. The O-cell™ was unloaded in three decrements and the test was concluded.

We applied the load increments using the Quick Load Test Method for Individual Piles (ASTM D1143 *Standard Test Method for Piles Under Static Axial Load*), holding each successive load increment constant for four minutes by manually adjusting the O-cell™ pressure. We typically used 30 to 60 seconds to move between increments. The data logger automatically recorded the instrument readings every 30 seconds, but herein we report only the 1, 2 and 4-minute readings during each increment of maintained load.

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## TEST RESULTS AND ANALYSES

**General:** The loads applied by the O-cell™ act in two opposing directions, resisted by the capacity of the shaft above and below. Theoretically, the O-cell™ does not impose an additional upward load until its expansion force exceeds the buoyant weight of the shaft above the O-cell™. Therefore, *net load*, which is defined as gross O-cell™ load minus the buoyant weight of the shaft above, is used to determine side shear resistance above the O-cell™ and to construct the equivalent top-loaded load-settlement. For this test we calculated a buoyant weight of shaft of 0.49 MN (110 kips) above the O-cell™.

**Side Shear Resistance:** The maximum upward applied *net load* to the upper side shear was 4.30 MN (967 kips) which occurred at load interval 1L-6 (Appendix A, Page 3, Figure 1). At this loading, the upward movement of the O-cell™ top was 30.61 mm (1.205 inches).

In order to assess the side shear resistance of the test shaft, loads are calculated based on the strain gage data (Appendix A, Page 4) and estimates of shaft stiffness (AE), which are presented below and in Appendix I. We used the ACI formula ($E_c=57000\sqrt{f'_c}$) to calculate an elastic modulus for the concrete, where $f'_c$ was reported to be 30.82 MPa (4,470 psi) on the day of the test. This, combined with the area of reinforcing steel, was used to determine an average pile stiffness (AE) of 44,300 MN (9,960,000 kips) above elevation +294.10 m (+964.9 feet), 33,200 MN (7,470,000) between elevations +294.10 m and +278.96 m (+915.2 feet) and 30,700 (6,900,000) below elevation +278.96 m. Alternately, we performed a tangent stiffness analysis to obtain the stiffness directly from the strain gage data (Appendix I). This method shows close agreement with the ACI stiffness estimate. Net unit shear values for loading increment 1L-6 follow in Table A:

**TABLE A: Average Net Unit Side Shear Values for 1L-6**

| Load Transfer Zone | Load Direction | Net Unit Side Shear * |
|---|---|---|
| Top of Concrete to Strain Gage Level 3 | ↑ | 30 kPa (0.6 ksf) |
| Strain Gage Level 3 to Strain Gage Level 2 | ↑ | 126 kPa (2.6 ksf) |
| Strain Gage Level 2 to O-cell™ | ↑ | 217 kPa (4.5 ksf) |
| O-cell™ to Strain Gage Level 1 | ↓ | 166 kPa (3.5 ksf) |

* For upward-loaded shear, the buoyant weight of shaft in each zone has been subtracted from the load shed in the respective zone above the O-cell™.

NOTE: Net unit shear values derived from the strain gages below the O-cell™ assembly may not be ultimate values. See Figure G-1 for net unit shear vs. O-cell™ displacement plots.

**End Bearing Resistance:** The maximum O-cell™ load applied to the combined end bearing and lower side shear was 4.79 MN (1,077 kips) which occurred at load interval 1L-6 (Appendix A, Page 3, Figure 1). At this loading, the average downward movement of the O-cell™ base was 6.82 mm (0.269 inches). The load taken in shear by the 3.99 meters (13.1 feet) shaft section below the O-cell™ is calculated to be 2.54 MN (570 kips) assuming an estimated unit side shear value of 166 kPa (3.5 ksf) and a nominal shaft diameter of 1,220 mm (48 inches). The unit end bearing at the base of the shaft is estimated to be 1926 kPa (40.2 ksf) at the above noted displacement.

**Creep Limit**: See Appendix D for our O-cell™ method for determining creep limit. The combined end bearing and lower side shear creep data (Appendix A, Page 3) indicate that no apparent creep limit was reached at a movement of -6.82 mm (-0.269 inches) (Figure 4). The upper side shear creep data (Appendix A, Page 3) indicate that a creep limit of 2.45 MN (551 kips) was reached at a movement of 3.24 mm (0.128 inches) (Figure 5). A top-loaded shaft will not begin significant creep until both components begin creep movement. This will occur at the maximum of the movements required to reach the creep limit for each component. We believe that significant creep for this shaft will not begin until a top loading exceeds 7.4 MN (1,667 kips) by some unknown amount.

**Equivalent Top Load**: Figure 2 presents the equivalent top-loaded load-settlement curves. The lighter curve, described in Procedure Part I of Appendix C, was generated by using the measured upward top of O-cell™ and downward base of O-cell™ data. The curve is extended out to a settlement of 30 mm (1.2 inches) by extrapolating the top of O-cell™ data (Appendix H). Because it is often an important component of the settlements involved, the equivalent top load curve requires an adjustment for the additional elastic compression that would occur in a top-load test. The darker curve as described in Procedure Part II of Appendix C includes this adjustment.

The test shaft was loaded to a combined side shear and end-bearing load of 9.1 MN (2,044 kips). For a top loading of 6.2 MN (1,391 kips), the adjusted test data indicate this shaft would settle approximately 6.3 mm (0.25 inches) of which 2.5 mm (0.10

inches) is estimated elastic compression. For a top loading of 8.3 MN (1,858 kips) the adjusted test data indicate this shaft would settle approximately 12.7 mm (0.50 inches) of which 3.4 mm (0.13 inches) is estimated elastic compression.

Note that, as explained previously, the equivalent top load curve applies to incremental loading durations of four minutes. Creep effects will reduce the ultimate resistance of both components and increase pile top movement for a given loading over longer times. The Engineer can estimate such additional creep effects by suitable extrapolation of time effects using the creep data presented herein. However, our experience suggests that such corrections are small and perhaps negligible for top loadings below the creep limit indicated in Figure 2.

**Shaft Compression Comparison**: The measured maximum shaft compression, averaged from two telltales, is 0.59 mm (0.023 inches) at 1L-6 (Appendix A, Page 1). Using an average upper shaft stiffness of 35,100 MN (7,890,000 kips) and the load distribution in Figure 3 at 1L-6, we calculated an elastic compression of 0.60 mm (0.024 inches) over the length of the compression telltales. We believe this close agreement provides good evidence that the values of the estimated shaft stiffness are reasonable and that the O-cell™ loaded the shaft in accord with its calibrations.

**Bottom Plate Tilt**: The three LVWDTs measuring O-cell™ expansion allow us to evaluate the differential opening of the O-cell™ (Appendix A, Page 2). We calculate a maximum differential expansion of 0.76 mm (0.03 inches) (0.04°) across the nominal 1,220-mm (48-inch) diameter of the cross-section of the shaft at the 1L-6 maximum loading.

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## POST-TEST O-CELL™ GROUTING

Since the test shaft is intended to carry structural loading (a "production shaft"), the contractor needs to fill the annular void in the shaft created outside the cell as a result of the expansion of the cell. The O-cell™ itself should also be filled. The shaft includes the piping to permit filling the O-cell™ and void with grout. If not already grouted, we recommend that this be done as soon as possible according to the procedures in Appendix J.

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## LIMITATIONS AND STANDARD OF CARE

The instrumentation, testing services and data analysis provided by LOADTEST, Inc., outlined in this report, were performed in accordance with the accepted standards of care recognized by professionals in the drilled shaft and foundation engineering industry.

Please note that some of the information contained in this report is based on data (i.e. shaft diameter, elevations and concrete strength) provided by others. The engineer, therefore, should come to his or her own conclusions with regard to the analyses as they depend on this information. In particular, LOADTEST, Inc. typically does not observe and record drilled shaft construction details to the level of precision that the project engineer may require. In many cases, we may not be present for the entire duration of shaft construction. Since construction technique can play a significant role in determining the load bearing capacity of a drilled shaft, the engineer should pay close attention to the drilled shaft construction details that were recorded elsewhere.

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We trust that this information will meet your current project needs. If you have any questions, please do not hesitate to contact us at 800-368-1138.

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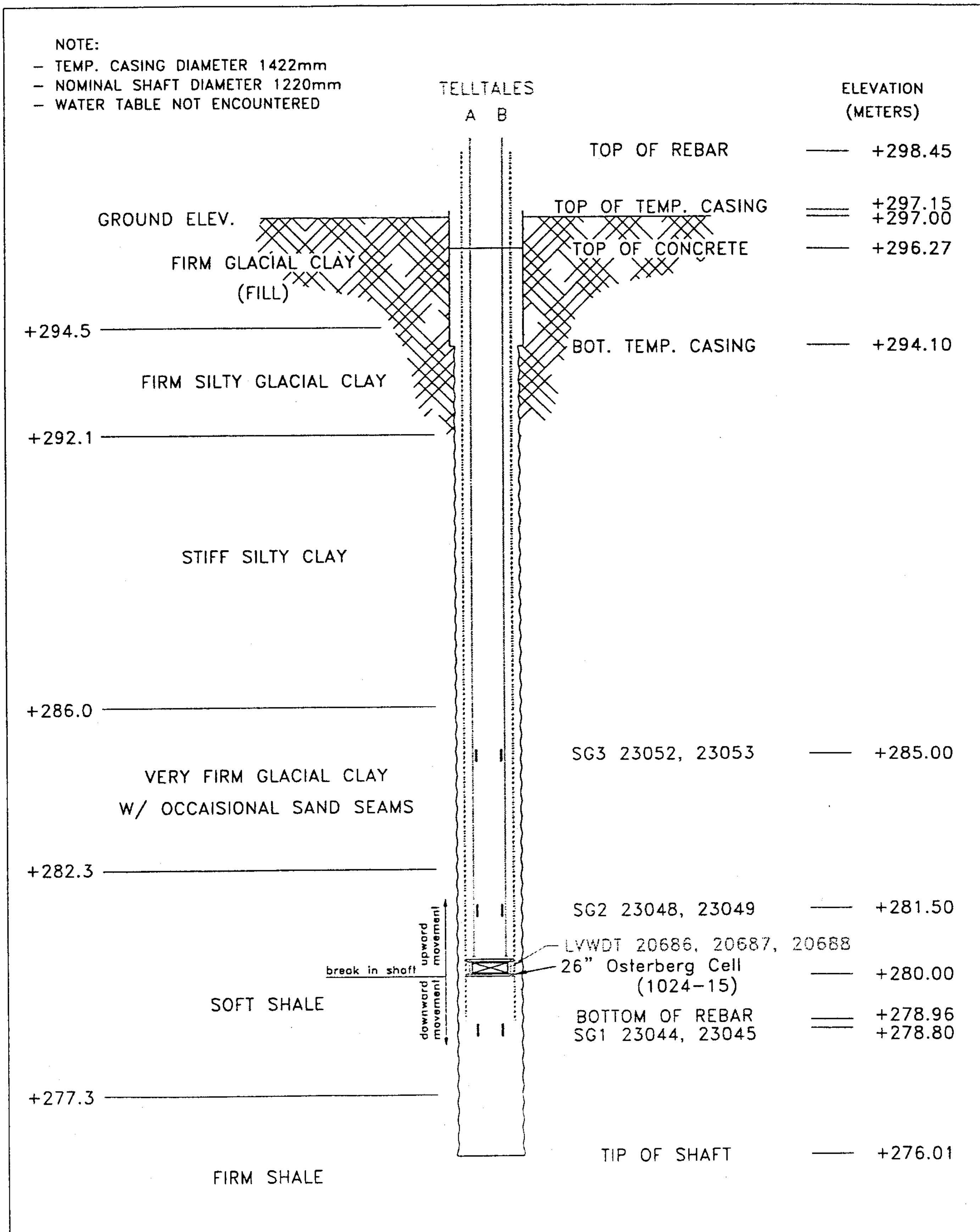
## TABLE B:
## SUMMARY OF DIMENSIONS, ELEVATIONS & SHAFT PROPERTIES

| | | | |
|---|---|---|---|
| **Shaft:** | | | |
| Nominal shaft diameter (EL +296.27 m to +294.10 m) | = | 1422 mm | 56 in |
| Nominal shaft diameter (EL +294.10 m to +276.01 m) | = | 1220 mm | 48 in |
| O-cell™: 1024-15 | = | 660 mm | 26 in |
| Bouyant weight of pile above base of O-cell™ | = | 0.49 MN | 110 kips |
| Estimated shaft stiffness, AE (EL +296.27 m to +294.10 m) | = | 44,300 MN | 9,960,000 kips |
| Estimated shaft stiffness, AE (EL +294.10 m to +278.96 m) | = | 33,200 MN | 7,470,000 kips |
| Estimated shaft stiffness, AE (EL +278.96 m to +276.01 m) | = | 30,700 MN | 6,900,000 kips |
| | | | |
| Elevation of ground surface | = | +297.00 m | +974.4 ft |
| Elevation of top of shaft concrete | = | +296.27 m | +972.0 ft |
| Elevation of base of O-cell™ (The break between upward and downward movement.) | = | +280.00 m | +918.6 ft |
| Elevation of shaft tip | = | +276.01 m | +905.6 ft |
| Elevation of water table | = | Not Encountered | |
| | | | |
| **Casings:** | | | |
| Elevation of top of outer temporary casing (1422 mm O.D.) | = | +297.15 m | +974.9 ft |
| Elevation of bottom of outer temporary casing (1422 mm O.D.) | = | +294.10 m | +964.9 ft |
| | | | |
| **Compression Sections:** | | | |
| Elevation of top of telltale used for shaft compression | = | +296.27 m | +972.0 ft |
| Elevation of bottom of telltale used for shaft compression | = | +280.35 m | +919.8 ft |
| | | | |
| **Strain Gages:** | | | |
| Elevation of strain gage Level 3 | = | +285.00 m | +935.0 ft |
| Elevation of strain gage Level 2 | = | +281.50 m | +923.6 ft |
| Elevation of strain gage Level 1 | = | +278.80 m | +914.7 ft |
| | | | |
| **Miscellaneous:** | | | |
| Top plate diameter (2 in thickness) | = | 959 mm | 37.8 in |
| Bottom plate diameter (2 in thickness) | = | 1035 mm | 40.8 in |
| ReBar size (18 No.) | = | M 32 | #10 |
| Spiral size (305 mm spacing) | = | M 16 | #5 |
| ReBar cage diameter | = | 1055 mm | 42 in |
| Unconfined compressive concrete strength | = | 30.8 MPa | 4470 psi |
| O-cell™ LVWDTs @ 0°, 180° and 290° with radius | = | 500 mm | 19.7 in |

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SCHEMATIC SECTION OF TEST SHAFT

LT–8756
I–235/42nd Overpass
Des Moines, Iowa

FIGURE A

# Osterberg Cell Load-Movement Curves

## Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA

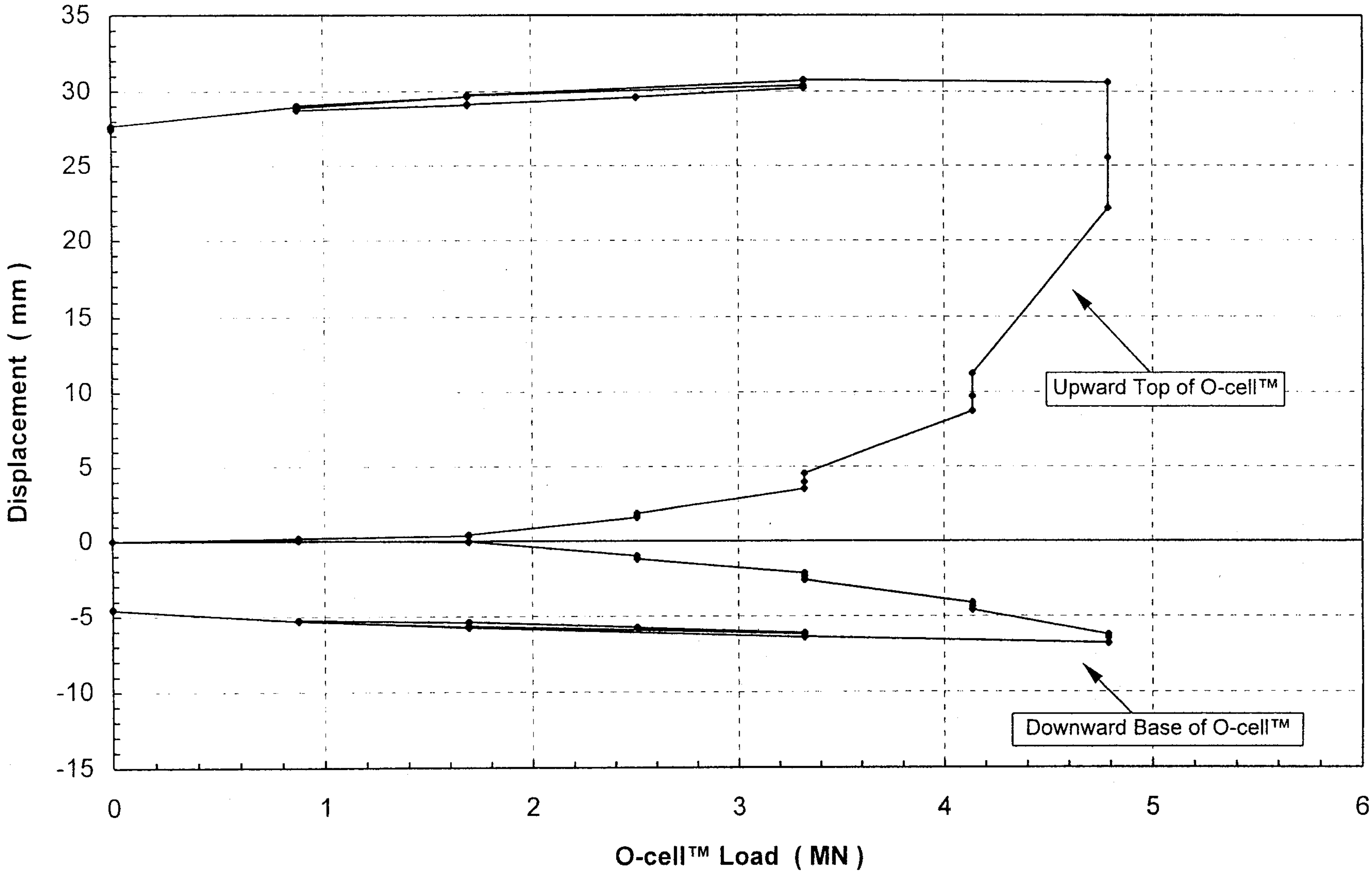


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Figure 1 of 5

# Equivalent Top Load Load-Movement Curve

## Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA

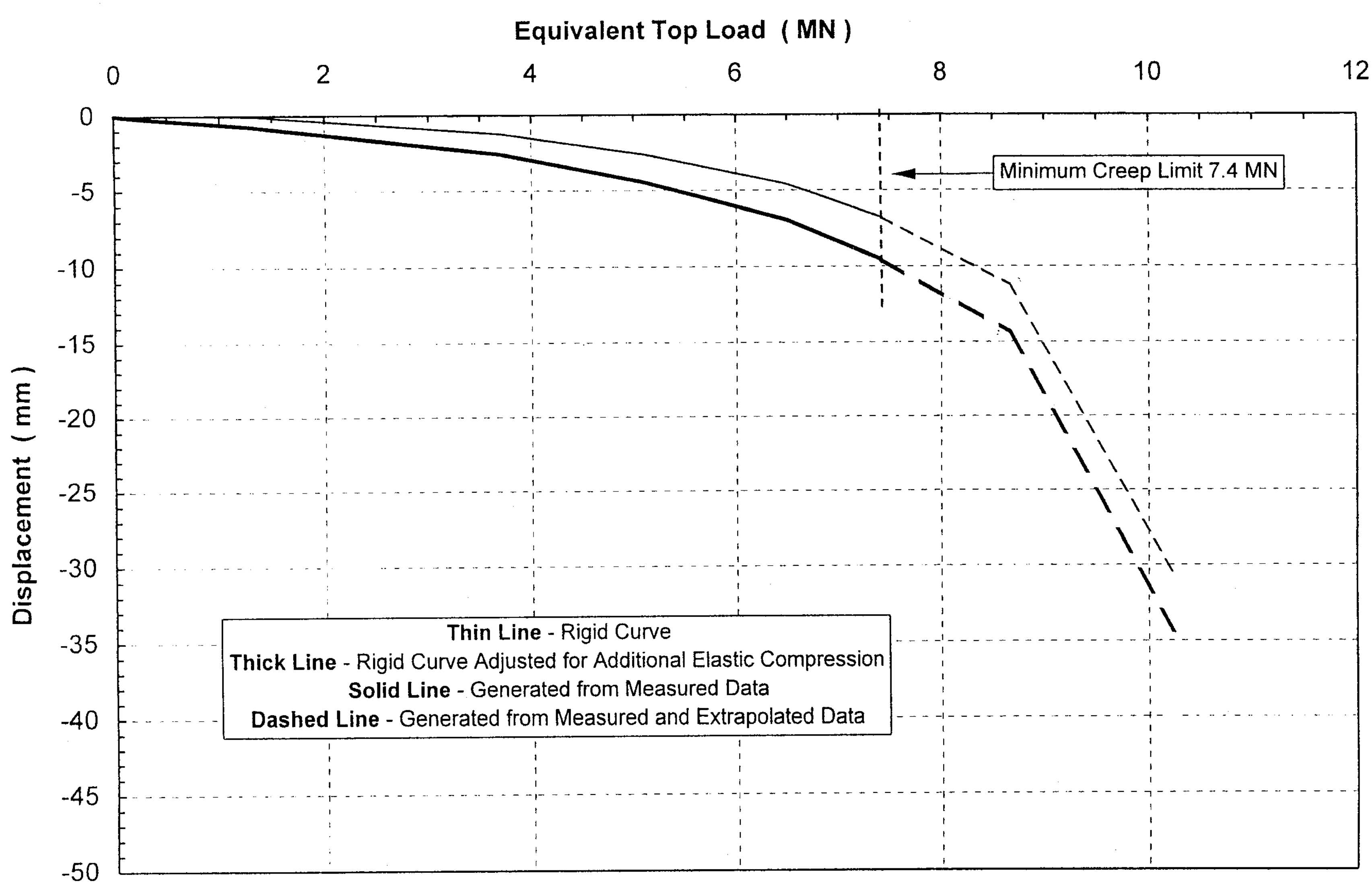


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**Figure 2 of 5**

## Strain Gage Load Distribution Curves

### Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA

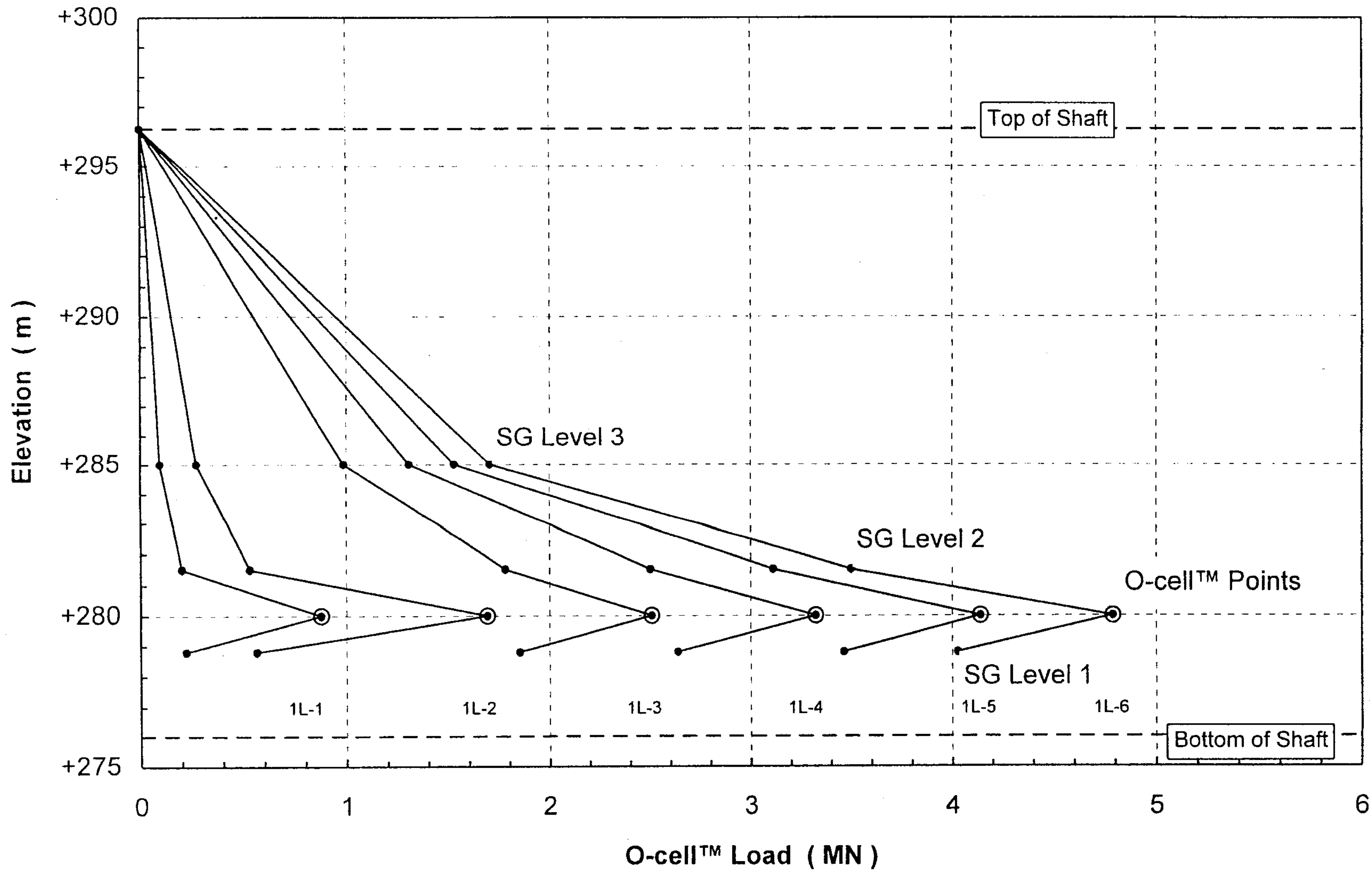




Figure 3 of 5

## Combined End Bearing and Lower Side Shear Creep Limit

### Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA

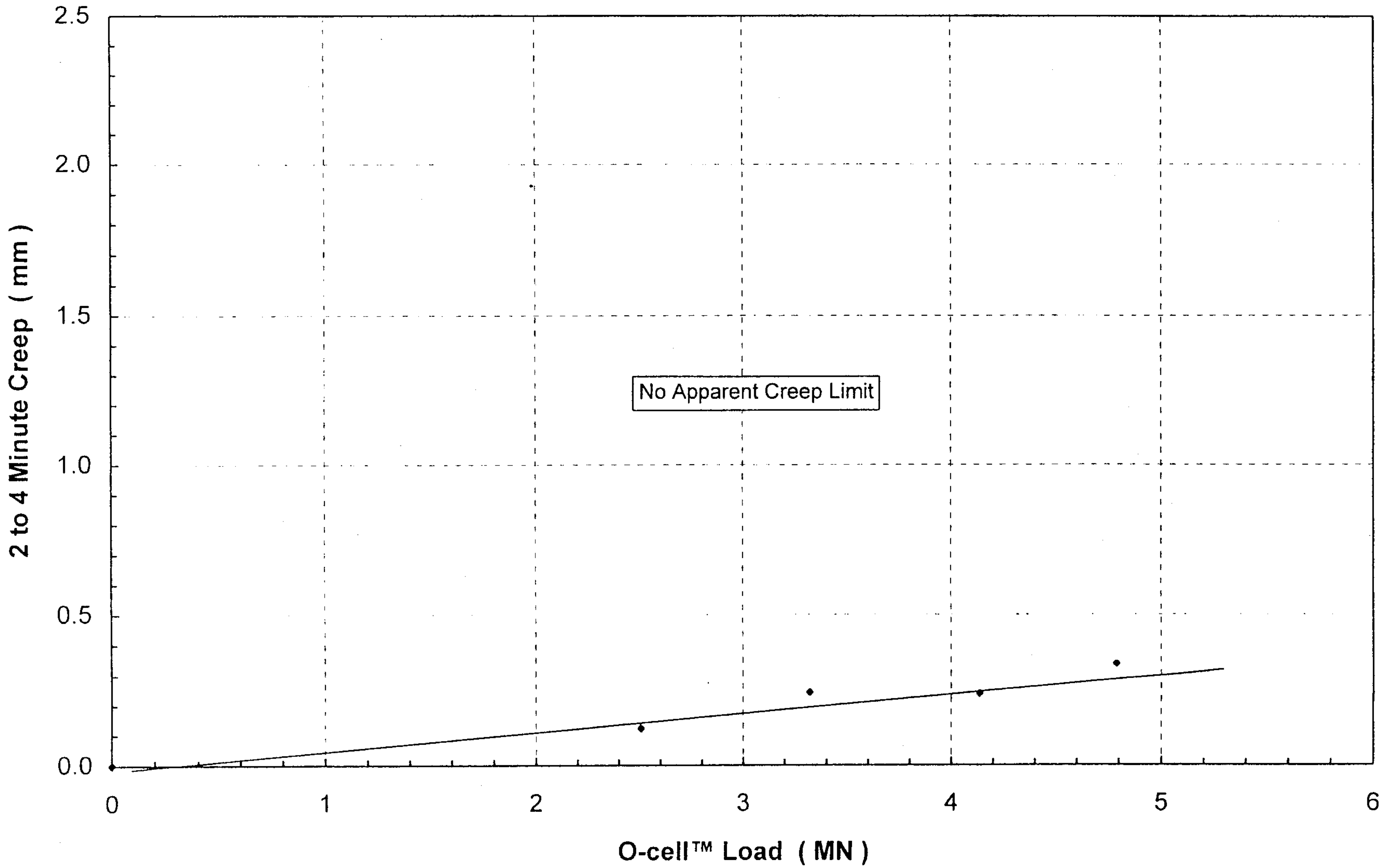


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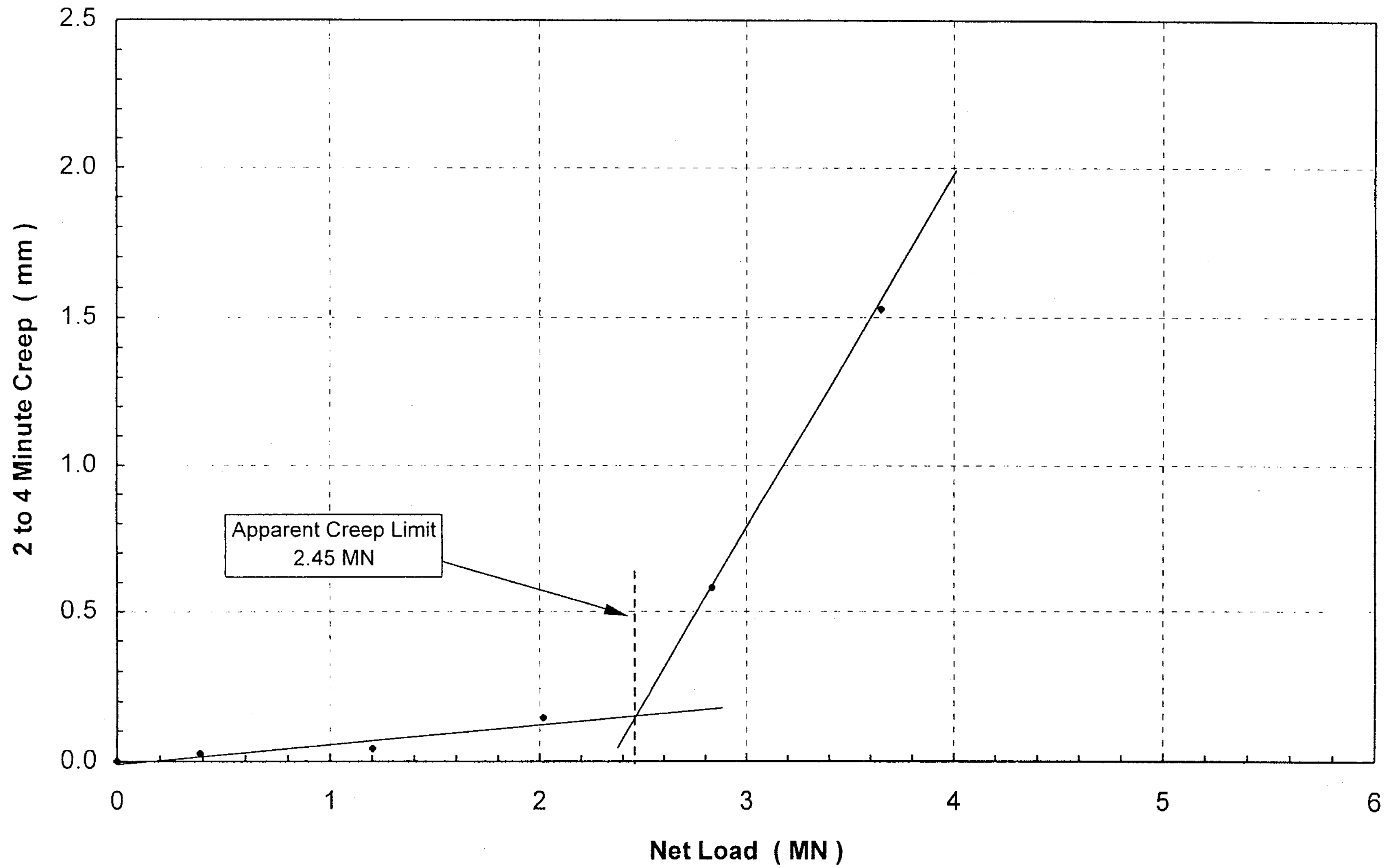
Figure 4 of 5

## Side Shear Creep Limit

### Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA



# APPENDIX A

## FIELD DATA & DATA REDUCTION

# Upward Top of Shaft Movement and Shaft Compression
## Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA

| Load Test Increment | Hold Time (minutes) | Time (h:m:s) | O-cell™ Pressure (psi) | O-cell™ Pressure (MPa) | O-cell™ Load (MN) | Ref. Beam * (mm) | Top of Shaft A (mm) | Top of Shaft B (mm) | Top of Shaft Average (mm) | Telltales A (mm) | Telltales B (mm) | Telltales Average (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 L - 0 | - | 11:58:00 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 L - 1 | 1 | 12:11:00 | 500 | 3.45 | 0.88 | 0.09 | 0.05 | 0.03 | 0.13 | 0.03 | 0.03 | 0.03 |
| 1 L - 1 | 2 | 12:12:00 | 500 | 3.45 | 0.88 | 0.10 | 0.05 | 0.03 | 0.14 | 0.03 | 0.03 | 0.03 |
| 1 L - 1 | 4 | 12:14:00 | 500 | 3.45 | 0.88 | 0.11 | 0.05 | 0.05 | 0.16 | 0.03 | 0.03 | 0.03 |
| 1 L - 2 | 1 | 12:15:30 | 1000 | 6.89 | 1.69 | 0.12 | 0.13 | 0.16 | 0.27 | 0.08 | 0.07 | 0.08 |
| 1 L - 2 | 2 | 12:16:30 | 1000 | 6.89 | 1.69 | 0.14 | 0.16 | 0.16 | 0.29 | 0.08 | 0.08 | 0.08 |
| 1 L - 2 | 4 | 12:18:30 | 1000 | 6.89 | 1.69 | 0.16 | 0.16 | 0.18 | 0.32 | 0.08 | 0.09 | 0.09 |
| 1 L - 3 | 1 | 12:20:00 | 1500 | 10.34 | 2.51 | 0.16 | 1.05 | 1.12 | 1.25 | 0.29 | 0.31 | 0.30 |
| 1 L - 3 | 2 | 12:21:00 | 1500 | 10.34 | 2.51 | 0.17 | 1.15 | 1.22 | 1.36 | 0.31 | 0.31 | 0.31 |
| 1 L - 3 | 4 | 12:23:00 | 1500 | 10.34 | 2.51 | 0.21 | 1.23 | 1.33 | 1.49 | 0.32 | 0.33 | 0.33 |
| 1 L - 4 | 1 | 12:24:30 | 2000 | 13.79 | 3.32 | 0.23 | 2.75 | 2.89 | 3.06 | 0.42 | 0.43 | 0.42 |
| 1 L - 4 | 2 | 12:25:30 | 2000 | 13.79 | 3.32 | 0.25 | 3.17 | 3.34 | 3.50 | 0.42 | 0.44 | 0.43 |
| 1 L - 4 | 4 | 12:27:30 | 2000 | 13.79 | 3.32 | 0.29 | 3.70 | 3.88 | 4.08 | 0.42 | 0.43 | 0.43 |
| 1 L - 5 | 1 | 12:29:30 | 2500 | 17.24 | 4.14 | 0.35 | 7.77 | 7.87 | 8.17 | 0.51 | 0.53 | 0.52 |
| 1 L - 5 | 2 | 12:30:30 | 2500 | 17.24 | 4.14 | 0.38 | 8.74 | 8.81 | 9.16 | 0.51 | 0.54 | 0.53 |
| 1 L - 5 | 4 | 12:32:30 | 2500 | 17.24 | 4.14 | 0.41 | 10.24 | 10.32 | 10.69 | 0.51 | 0.54 | 0.52 |
| 1 L - 6 | 1 | 12:35:00 | 2900 | 19.99 | 4.79 | 0.42 | 21.08 | 21.15 | 21.53 | 0.57 | 0.61 | 0.59 |
| 1 L - 6 | 2 | 12:36:00 | 2900 | 19.99 | 4.79 | 0.42 | 24.49 | 24.54 | 24.93 | 0.56 | 0.62 | 0.59 |
| 1 L - 6 | 4 | 12:38:00 | 2900 | 19.99 | 4.79 | 0.40 | 29.58 | 29.65 | 30.02 | 0.55 | 0.62 | 0.59 |
| 1 U - 1 | 1 | 12:39:30 | 2000 | 13.79 | 3.32 | 0.39 | 29.90 | 29.99 | 30.33 | 0.42 | 0.48 | 0.45 |
| 1 U - 1 | 2 | 12:40:30 | 2000 | 13.79 | 3.32 | 0.38 | 29.90 | 29.99 | 30.32 | 0.42 | 0.47 | 0.44 |
| 1 U - 1 | 4 | 12:42:30 | 2000 | 13.79 | 3.32 | 0.35 | 29.87 | 29.99 | 30.29 | 0.42 | 0.47 | 0.44 |
| 1 U - 2 | 1 | 12:44:00 | 1000 | 6.89 | 1.69 | 0.34 | 29.08 | 29.21 | 29.48 | 0.23 | 0.27 | 0.25 |
| 1 U - 2 | 2 | 12:45:00 | 1000 | 6.89 | 1.69 | 0.33 | 29.06 | 29.18 | 29.45 | 0.22 | 0.28 | 0.25 |
| 1 U - 2 | 4 | 12:47:00 | 1000 | 6.89 | 1.69 | 0.30 | 29.03 | 29.15 | 29.39 | 0.21 | 0.27 | 0.24 |
| 1 U - 3 | 1 | 12:48:30 | 500 | 3.45 | 0.88 | 0.27 | 28.40 | 28.53 | 28.73 | 0.12 | 0.17 | 0.14 |
| 1 U - 3 | 2 | 12:49:30 | 500 | 3.45 | 0.88 | 0.25 | 28.32 | 28.42 | 28.63 | 0.11 | 0.17 | 0.14 |
| 1 U - 3 | 4 | 12:51:30 | 500 | 3.45 | 0.88 | 0.25 | 28.27 | 28.40 | 28.59 | 0.10 | 0.17 | 0.13 |
| 2 L - 1 | 1 | 12:54:00 | 1000 | 6.89 | 1.69 | 0.33 | 28.45 | 28.61 | 28.86 | 0.18 | 0.25 | 0.21 |
| 2 L - 1 | 2 | 12:55:00 | 1000 | 6.89 | 1.69 | 0.36 | 28.45 | 28.58 | 28.87 | 0.18 | 0.25 | 0.21 |
| 2 L - 1 | 4 | 12:57:00 | 1000 | 6.89 | 1.69 | 0.40 | 28.45 | 28.58 | 28.91 | 0.18 | 0.25 | 0.21 |
| 2 L - 2 | 1 | 12:58:30 | 1500 | 10.34 | 2.51 | 0.41 | 28.82 | 28.92 | 29.28 | 0.27 | 0.34 | 0.31 |
| 2 L - 2 | 2 | 12:59:30 | 1500 | 10.34 | 2.51 | 0.41 | 28.79 | 28.95 | 29.28 | 0.28 | 0.34 | 0.31 |
| 2 L - 2 | 4 | 13:01:30 | 1500 | 10.34 | 2.51 | 0.43 | 28.79 | 28.95 | 29.30 | 0.27 | 0.35 | 0.31 |
| 2 L - 3 | 1 | 13:03:00 | 2000 | 13.79 | 3.32 | 0.46 | 29.29 | 29.44 | 29.83 | 0.36 | 0.44 | 0.40 |
| 2 L - 3 | 2 | 13:04:00 | 2000 | 13.79 | 3.32 | 0.48 | 29.32 | 29.47 | 29.88 | 0.36 | 0.45 | 0.41 |
| 2 L - 3 | 4 | 13:06:00 | 2000 | 13.79 | 3.32 | 0.51 | 29.35 | 29.49 | 29.92 | 0.37 | 0.46 | 0.41 |
| 2 L - 3 | 8 | 13:10:00 | 2000 | 13.79 | 3.32 | 0.51 | 29.40 | 29.57 | 29.99 | 0.38 | 0.46 | 0.42 |
| 2 U - 1 | 1 | 13:11:30 | 1000 | 6.89 | 1.69 | 0.49 | 28.87 | 29.05 | 29.45 | 0.22 | 0.28 | 0.25 |
| 2 U - 1 | 2 | 13:12:30 | 1000 | 6.89 | 1.69 | 0.47 | 28.87 | 29.02 | 29.42 | 0.21 | 0.28 | 0.25 |
| 2 U - 1 | 4 | 13:14:30 | 1000 | 6.89 | 1.69 | 0.44 | 28.85 | 29.02 | 29.37 | 0.21 | 0.28 | 0.25 |
| 2 U - 2 | 1 | 13:16:00 | 500 | 3.45 | 0.88 | 0.42 | 28.37 | 28.55 | 28.89 | 0.11 | 0.18 | 0.14 |
| 2 U - 2 | 2 | 13:17:00 | 500 | 3.45 | 0.88 | 0.42 | 28.35 | 28.53 | 28.85 | 0.11 | 0.18 | 0.14 |
| 2 U - 2 | 4 | 13:19:00 | 500 | 3.45 | 0.88 | 0.39 | 28.32 | 28.50 | 28.80 | 0.10 | 0.19 | 0.14 |
| 2 U - 3 | 1 | 13:20:30 | 0 | 0.00 | 0.00 | 0.36 | 27.19 | 27.38 | 27.65 | -0.01 | 0.06 | 0.02 |
| 2 U - 3 | 2 | 13:21:30 | 0 | 0.00 | 0.00 | 0.35 | 27.11 | 27.30 | 27.56 | -0.01 | 0.06 | 0.02 |
| 2 U - 3 | 4 | 13:23:30 | 0 | 0.00 | 0.00 | 0.34 | 27.06 | 27.25 | 27.50 | -0.03 | 0.06 | 0.02 |
| 2 U - 3 | 8 | 13:27:30 | 0 | 0.00 | 0.00 | 0.33 | 26.98 | 27.17 | 27.40 | -0.03 | 0.05 | 0.01 |

* Positive values indicate upward reference beam movement.

## O-cell™ Expansion

### Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA

| Load Test Increment | Hold Time (minutes) | Time (h:m:s) | O-cell™ Pressure (MPa) | O-cell™ Load (MN) | O-cell™ Expansion LVWDT 20686 (mm) | LVWDT 20687 (mm) | LVWDT 20688 * (mm) | Average (mm) |
|---|---|---|---|---|---|---|---|---|
| 1 L - 0 | - | 11:58:00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 L - 1 | 1 | 12:11:00 | 3.45 | 0.88 | 0.15 | 0.14 | 0.18 | 0.14 |
| 1 L - 1 | 2 | 12:12:00 | 3.45 | 0.88 | 0.15 | 0.15 | 0.18 | 0.15 |
| 1 L - 1 | 4 | 12:14:00 | 3.45 | 0.88 | 0.15 | 0.15 | 0.16 | 0.15 |
| 1 L - 2 | 1 | 12:15:30 | 6.89 | 1.69 | 0.42 | 0.41 | 0.46 | 0.41 |
| 1 L - 2 | 2 | 12:16:30 | 6.89 | 1.69 | 0.44 | 0.42 | 0.48 | 0.43 |
| 1 L - 2 | 4 | 12:18:30 | 6.89 | 1.69 | 0.46 | 0.44 | 0.50 | 0.45 |
| 1 L - 3 | 1 | 12:20:00 | 10.34 | 2.51 | 2.58 | 2.55 | 2.65 | 2.56 |
| 1 L - 3 | 2 | 12:21:00 | 10.34 | 2.51 | 2.78 | 2.76 | 2.85 | 2.77 |
| 1 L - 3 | 4 | 12:23:00 | 10.34 | 2.51 | 3.05 | 3.02 | 3.14 | 3.03 |
| 1 L - 4 | 1 | 12:24:30 | 13.79 | 3.32 | 5.70 | 5.61 | 5.81 | 5.65 |
| 1 L - 4 | 2 | 12:25:30 | 13.79 | 3.32 | 6.34 | 6.28 | 6.45 | 6.31 |
| 1 L - 4 | 4 | 12:27:30 | 13.79 | 3.32 | 7.16 | 7.10 | 7.28 | 7.13 |
| 1 L - 5 | 1 | 12:29:30 | 17.24 | 4.14 | 12.87 | 12.79 | 13.05 | 12.83 |
| 1 L - 5 | 2 | 12:30:30 | 17.24 | 4.14 | 14.10 | 14.01 | 14.26 | 14.05 |
| 1 L - 5 | 4 | 12:32:30 | 17.24 | 4.14 | 15.88 | 15.76 | 16.07 | 15.82 |
| 1 L - 6 | 1 | 12:35:00 | 19.99 | 4.79 | 28.43 | 28.35 | 28.72 | 28.39 |
| 1 L - 6 | 2 | 12:36:00 | 19.99 | 4.79 | 32.06 | 31.95 | 32.33 | 32.00 |
| 1 L - 6 | 4 | 12:38:00 | 19.99 | 4.79 | 37.46 | 37.39 | 37.73 | 37.43 |
| 1 U - 1 | 1 | 12:39:30 | 13.79 | 3.32 | 37.24 | 37.13 | 37.42 | 37.19 |
| 1 U - 1 | 2 | 12:40:30 | 13.79 | 3.32 | 37.22 | 37.10 | 37.40 | 37.16 |
| 1 U - 1 | 4 | 12:42:30 | 13.79 | 3.32 | 37.22 | 37.10 | 37.40 | 37.16 |
| 1 U - 2 | 1 | 12:44:00 | 6.89 | 1.69 | 35.54 | 35.43 | 35.68 | 35.49 |
| 1 U - 2 | 2 | 12:45:00 | 6.89 | 1.69 | 35.49 | 35.40 | 35.64 | 35.45 |
| 1 U - 2 | 4 | 12:47:00 | 6.89 | 1.69 | 35.44 | 35.36 | 35.60 | 35.40 |
| 1 U - 3 | 1 | 12:48:30 | 3.45 | 0.88 | 34.21 | 34.15 | 34.33 | 34.18 |
| 1 U - 3 | 2 | 12:49:30 | 3.45 | 0.88 | 34.07 | 34.00 | 34.20 | 34.04 |
| 1 U - 3 | 4 | 12:51:30 | 3.45 | 0.88 | 34.03 | 33.93 | 34.13 | 33.98 |
| 2 L - 1 | 1 | 12:54:00 | 6.89 | 1.69 | 34.54 | 34.44 | 34.65 | 34.49 |
| 2 L - 1 | 2 | 12:55:00 | 6.89 | 1.69 | 34.54 | 34.47 | 34.65 | 34.51 |
| 2 L - 1 | 4 | 12:57:00 | 6.89 | 1.69 | 34.57 | 34.45 | 34.68 | 34.51 |
| 2 L - 2 | 1 | 12:58:30 | 10.34 | 2.51 | 35.37 | 35.28 | 35.53 | 35.33 |
| 2 L - 2 | 2 | 12:59:30 | 10.34 | 2.51 | 35.41 | 35.32 | 35.57 | 35.36 |
| 2 L - 2 | 4 | 13:01:30 | 10.34 | 2.51 | 35.43 | 35.34 | 35.59 | 35.39 |
| 2 L - 3 | 1 | 13:03:00 | 13.79 | 3.32 | 36.43 | 36.31 | 36.59 | 36.37 |
| 2 L - 3 | 2 | 13:04:00 | 13.79 | 3.32 | 36.51 | 36.39 | 36.66 | 36.45 |
| 2 L - 3 | 4 | 13:06:00 | 13.79 | 3.32 | 36.57 | 36.45 | 36.74 | 36.51 |
| 2 L - 3 | 8 | 13:10:00 | 13.79 | 3.32 | 36.65 | 36.55 | 36.83 | 36.60 |
| 2 U - 1 | 1 | 13:11:30 | 6.89 | 1.69 | 35.41 | 35.35 | 35.58 | 35.38 |
| 2 U - 1 | 2 | 13:12:30 | 6.89 | 1.69 | 35.39 | 35.33 | 35.56 | 35.36 |
| 2 U - 1 | 4 | 13:14:30 | 6.89 | 1.69 | 35.38 | 35.30 | 35.55 | 35.34 |
| 2 U - 2 | 1 | 13:16:00 | 3.45 | 0.88 | 34.39 | 34.33 | 34.49 | 34.36 |
| 2 U - 2 | 2 | 13:17:00 | 3.45 | 0.88 | 34.36 | 34.27 | 34.46 | 34.31 |
| 2 U - 2 | 4 | 13:19:00 | 3.45 | 0.88 | 34.31 | 34.23 | 34.42 | 34.27 |
| 2 U - 3 | 1 | 13:20:30 | 0.00 | 0.00 | 32.30 | 32.20 | 32.39 | 32.25 |
| 2 U - 3 | 2 | 13:21:30 | 0.00 | 0.00 | 32.20 | 32.09 | 32.23 | 32.14 |
| 2 U - 3 | 4 | 13:23:30 | 0.00 | 0.00 | 32.08 | 32.00 | 32.18 | 32.04 |
| 2 U - 3 | 8 | 13:27:30 | 0.00 | 0.00 | 31.94 | 31.86 | 32.02 | 31.90 |

* LVWDT 20688 is not included in the average due to its orientation. LVWDTs 20686 and 20687 are opposed 180°.

## Upward and Downward O-cell™ Plate Movement and Creep (calculated)
## Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA

| Load Test Increment | Hold Time (minutes) | Time (h:m:s) | O-cell™ Pressure (MPa) | O-cell™ Load (MN) | Top of Shaft (mm) | Total Comp. (mm) | Top Plate Movement (mm) | O-cell™ Expansion (mm) | Bot. Plate Movement (mm) | Creep Up Per Hold (mm) | Creep Dn Per Hold (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 L - 0 | - | 11:58:00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | |
| 1 L - 1 | 1 | 12:11:00 | 3.45 | 0.88 | 0.13 | 0.03 | 0.17 | 0.14 | 0.02 | | |
| 1 L - 1 | 2 | 12:12:00 | 3.45 | 0.88 | 0.14 | 0.03 | 0.17 | 0.15 | 0.01 | 0.00 | 0.01 |
| 1 L - 1 | 4 | 12:14:00 | 3.45 | 0.88 | 0.16 | 0.03 | 0.19 | 0.15 | 0.04 | 0.03 | -0.03 |
| 1 L - 2 | 1 | 12:15:30 | 6.89 | 1.69 | 0.27 | 0.08 | 0.34 | 0.41 | -0.07 | | |
| 1 L - 2 | 2 | 12:16:30 | 6.89 | 1.69 | 0.29 | 0.08 | 0.37 | 0.43 | -0.06 | 0.03 | -0.01 |
| 1 L - 2 | 4 | 12:18:30 | 6.89 | 1.69 | 0.32 | 0.09 | 0.41 | 0.45 | -0.04 | 0.04 | -0.02 |
| 1 L - 3 | 1 | 12:20:00 | 10.34 | 2.51 | 1.25 | 0.30 | 1.55 | 2.56 | -1.02 | | |
| 1 L - 3 | 2 | 12:21:00 | 10.34 | 2.51 | 1.36 | 0.31 | 1.67 | 2.77 | -1.10 | 0.12 | 0.08 |
| 1 L - 3 | 4 | 12:23:00 | 10.34 | 2.51 | 1.49 | 0.33 | 1.81 | 3.03 | -1.22 | 0.14 | 0.12 |
| 1 L - 4 | 1 | 12:24:30 | 13.79 | 3.32 | 3.06 | 0.42 | 3.48 | 5.65 | -2.17 | | |
| 1 L - 4 | 2 | 12:25:30 | 13.79 | 3.32 | 3.50 | 0.43 | 3.93 | 6.31 | -2.38 | 0.45 | 0.21 |
| 1 L - 4 | 4 | 12:27:30 | 13.79 | 3.32 | 4.08 | 0.43 | 4.51 | 7.13 | -2.62 | 0.58 | 0.24 |
| 1 L - 5 | 1 | 12:29:30 | 17.24 | 4.14 | 8.17 | 0.52 | 8.70 | 12.83 | -4.13 | | |
| 1 L - 5 | 2 | 12:30:30 | 17.24 | 4.14 | 9.16 | 0.53 | 9.68 | 14.05 | -4.37 | 0.99 | 0.24 |
| 1 L - 5 | 4 | 12:32:30 | 17.24 | 4.14 | 10.69 | 0.52 | 11.21 | 15.82 | -4.60 | 1.53 | 0.24 |
| 1 L - 6 | 1 | 12:35:00 | 19.99 | 4.79 | 21.53 | 0.59 | 22.13 | 28.39 | -6.27 | | |
| 1 L - 6 | 2 | 12:36:00 | 19.99 | 4.79 | 24.93 | 0.59 | 25.52 | 32.00 | -6.48 | 3.39 | 0.22 |
| 1 L - 6 | 4 | 12:38:00 | 19.99 | 4.79 | 30.02 | 0.59 | 30.61 | 37.43 | -6.82 | 5.09 | 0.34 |
| 1 U - 1 | 1 | 12:39:30 | 13.79 | 3.32 | 30.33 | 0.45 | 30.78 | 37.19 | -6.40 | | |
| 1 U - 1 | 2 | 12:40:30 | 13.79 | 3.32 | 30.32 | 0.44 | 30.77 | 37.16 | -6.39 | | |
| 1 U - 1 | 4 | 12:42:30 | 13.79 | 3.32 | 30.29 | 0.44 | 30.73 | 37.16 | -6.43 | | |
| 1 U - 2 | 1 | 12:44:00 | 6.89 | 1.69 | 29.48 | 0.25 | 29.73 | 35.49 | -5.76 | | |
| 1 U - 2 | 2 | 12:45:00 | 6.89 | 1.69 | 29.45 | 0.25 | 29.70 | 35.45 | -5.75 | | |
| 1 U - 2 | 4 | 12:47:00 | 6.89 | 1.69 | 29.39 | 0.24 | 29.63 | 35.40 | -5.77 | | |
| 1 U - 3 | 1 | 12:48:30 | 3.45 | 0.88 | 28.73 | 0.14 | 28.88 | 34.18 | -5.30 | | |
| 1 U - 3 | 2 | 12:49:30 | 3.45 | 0.88 | 28.63 | 0.14 | 28.76 | 34.04 | -5.27 | | |
| 1 U - 3 | 4 | 12:51:30 | 3.45 | 0.88 | 28.59 | 0.13 | 28.72 | 33.98 | -5.26 | | |
| 2 L - 1 | 1 | 12:54:00 | 6.89 | 1.69 | 28.86 | 0.21 | 29.07 | 34.49 | -5.42 | | |
| 2 L - 1 | 2 | 12:55:00 | 6.89 | 1.69 | 28.87 | 0.21 | 29.09 | 34.51 | -5.42 | | |
| 2 L - 1 | 4 | 12:57:00 | 6.89 | 1.69 | 28.91 | 0.21 | 29.13 | 34.51 | -5.38 | | |
| 2 L - 2 | 1 | 12:58:30 | 10.34 | 2.51 | 29.28 | 0.31 | 29.59 | 35.33 | -5.74 | | |
| 2 L - 2 | 2 | 12:59:30 | 10.34 | 2.51 | 29.28 | 0.31 | 29.59 | 35.36 | -5.77 | | |
| 2 L - 2 | 4 | 13:01:30 | 10.34 | 2.51 | 29.30 | 0.31 | 29.61 | 35.39 | -5.77 | | |
| 2 L - 3 | 1 | 13:03:00 | 13.79 | 3.32 | 29.83 | 0.40 | 30.23 | 36.37 | -6.14 | | |
| 2 L - 3 | 2 | 13:04:00 | 13.79 | 3.32 | 29.88 | 0.41 | 30.28 | 36.45 | -6.16 | | |
| 2 L - 3 | 4 | 13:06:00 | 13.79 | 3.32 | 29.92 | 0.41 | 30.34 | 36.51 | -6.17 | | |
| 2 L - 3 | 8 | 13:10:00 | 13.79 | 3.32 | 29.99 | 0.42 | 30.41 | 36.60 | -6.19 | | |
| 2 U - 1 | 1 | 13:11:30 | 6.89 | 1.69 | 29.45 | 0.25 | 29.71 | 35.38 | -5.67 | | |
| 2 U - 1 | 2 | 13:12:30 | 6.89 | 1.69 | 29.42 | 0.25 | 29.67 | 35.36 | -5.69 | | |
| 2 U - 1 | 4 | 13:14:30 | 6.89 | 1.69 | 29.37 | 0.25 | 29.62 | 35.34 | -5.72 | | |
| 2 U - 2 | 1 | 13:16:00 | 3.45 | 0.88 | 28.89 | 0.14 | 29.03 | 34.36 | -5.33 | | |
| 2 U - 2 | 2 | 13:17:00 | 3.45 | 0.88 | 28.85 | 0.14 | 29.00 | 34.31 | -5.31 | | |
| 2 U - 2 | 4 | 13:19:00 | 3.45 | 0.88 | 28.80 | 0.14 | 28.94 | 34.27 | -5.33 | | |
| 2 U - 3 | 1 | 13:20:30 | 0.00 | 0.00 | 27.65 | 0.02 | 27.67 | 32.25 | -4.58 | | |
| 2 U - 3 | 2 | 13:21:30 | 0.00 | 0.00 | 27.56 | 0.02 | 27.58 | 32.14 | -4.56 | | |
| 2 U - 3 | 4 | 13:23:30 | 0.00 | 0.00 | 27.50 | 0.02 | 27.51 | 32.04 | -4.53 | | |
| 2 U - 3 | 8 | 13:27:30 | 0.00 | 0.00 | 27.40 | 0.01 | 27.41 | 31.90 | -4.49 | | |

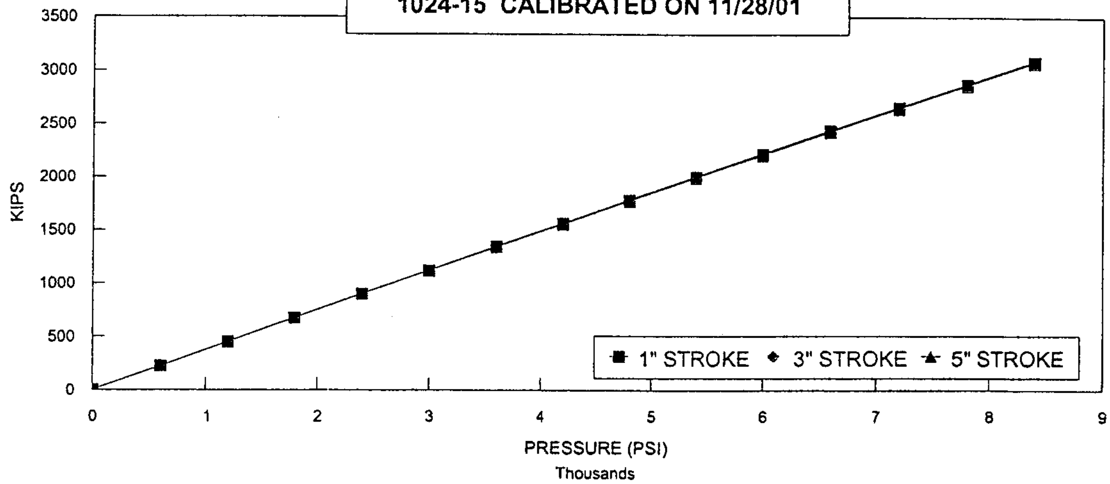
## Strain Gage Readings and Loads at Levels 1, 2 and 3
## Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA

| Load Test Increment | Hold Time (minutes) | Time (h:m:s) | O-cell™ | | Level 1 | | | Level 2 | | | Level 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pressure (MPa) | Load (MN) | 23044 (με) | 23045 (με) | Av. Load (MN) | 23048 (με) | 23049 (με) | Av. Load (MN) | 23052 (με) | 23053 (με) | Av. Load (MN) |
| 1 L - 0 | - | 11:58:00 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 1 L - 1 | 1 | 12:11:00 | 3.45 | 0.88 | 9 | 5 | 0.22 | 8 | 4 | 0.19 | 3 | 3 | 0.09 |
| 1 L - 1 | 2 | 12:12:00 | 3.45 | 0.88 | 9 | 5 | 0.22 | 8 | 4 | 0.19 | 3 | 3 | 0.09 |
| 1 L - 1 | 4 | 12:14:00 | 3.45 | 0.88 | 9 | 5 | 0.22 | 8 | 4 | 0.20 | 3 | 3 | 0.09 |
| 1 L - 2 | 1 | 12:15:30 | 6.89 | 1.69 | 21 | 14 | 0.54 | 19 | 12 | 0.51 | 8 | 7 | 0.25 |
| 1 L - 2 | 2 | 12:16:30 | 6.89 | 1.69 | 22 | 14 | 0.55 | 19 | 11 | 0.51 | 8 | 7 | 0.26 |
| 1 L - 2 | 4 | 12:18:30 | 6.89 | 1.69 | 22 | 15 | 0.56 | 20 | 12 | 0.53 | 8 | 8 | 0.27 |
| 1 L - 3 | 1 | 12:20:00 | 10.34 | 2.51 | 60 | 53 | 1.75 | 59 | 42 | 1.68 | 30 | 26 | 0.93 |
| 1 L - 3 | 2 | 12:21:00 | 10.34 | 2.51 | 62 | 55 | 1.79 | 61 | 43 | 1.72 | 31 | 26 | 0.94 |
| 1 L - 3 | 4 | 12:23:00 | 10.34 | 2.51 | 63 | 57 | 1.85 | 63 | 44 | 1.78 | 32 | 27 | 0.99 |
| 1 L - 4 | 1 | 12:24:30 | 13.79 | 3.32 | 84 | 80 | 2.51 | 86 | 59 | 2.42 | 41 | 35 | 1.26 |
| 1 L - 4 | 2 | 12:25:30 | 13.79 | 3.32 | 85 | 82 | 2.57 | 87 | 61 | 2.45 | 41 | 35 | 1.26 |
| 1 L - 4 | 4 | 12:27:30 | 13.79 | 3.32 | 86 | 86 | 2.64 | 89 | 62 | 2.50 | 43 | 36 | 1.30 |
| 1 L - 5 | 1 | 12:29:30 | 17.24 | 4.14 | 111 | 108 | 3.36 | 110 | 76 | 3.09 | 50 | 43 | 1.55 |
| 1 L - 5 | 2 | 12:30:30 | 17.24 | 4.14 | 112 | 109 | 3.40 | 110 | 76 | 3.10 | 50 | 43 | 1.54 |
| 1 L - 5 | 4 | 12:32:30 | 17.24 | 4.14 | 115 | 111 | 3.46 | 110 | 78 | 3.11 | 49 | 43 | 1.53 |
| 1 L - 6 | 1 | 12:35:00 | 19.99 | 4.79 | 131 | 129 | 3.99 | 125 | 87 | 3.52 | 51 | 53 | 1.73 |
| 1 L - 6 | 2 | 12:36:00 | 19.99 | 4.79 | 131 | 130 | 4.00 | 124 | 86 | 3.50 | 49 | 54 | 1.71 |
| 1 L - 6 | 4 | 12:38:00 | 19.99 | 4.79 | 131 | 131 | 4.03 | 124 | 87 | 3.50 | 48 | 55 | 1.71 |
| 1 U - 1 | 1 | 12:39:30 | 13.79 | 3.32 | 99 | 103 | 3.10 | 95 | 62 | 2.62 | 34 | 43 | 1.27 |
| 1 U - 1 | 2 | 12:40:30 | 13.79 | 3.32 | 97 | 102 | 3.06 | 94 | 62 | 2.59 | 33 | 42 | 1.25 |
| 1 U - 1 | 4 | 12:42:30 | 13.79 | 3.32 | 97 | 101 | 3.05 | 94 | 61 | 2.58 | 33 | 42 | 1.25 |
| 1 U - 2 | 1 | 12:44:00 | 6.89 | 1.69 | 53 | 62 | 1.77 | 55 | 29 | 1.39 | 15 | 24 | 0.65 |
| 1 U - 2 | 2 | 12:45:00 | 6.89 | 1.69 | 53 | 62 | 1.76 | 54 | 29 | 1.38 | 15 | 23 | 0.64 |
| 1 U - 2 | 4 | 12:47:00 | 6.89 | 1.69 | 52 | 62 | 1.74 | 54 | 29 | 1.37 | 15 | 23 | 0.63 |
| 1 U - 3 | 1 | 12:48:30 | 3.45 | 0.88 | 30 | 41 | 1.09 | 34 | 13 | 0.79 | 7 | 14 | 0.35 |
| 1 U - 3 | 2 | 12:49:30 | 3.45 | 0.88 | 27 | 39 | 1.02 | 32 | 12 | 0.73 | 6 | 13 | 0.31 |
| 1 U - 3 | 4 | 12:51:30 | 3.45 | 0.88 | 27 | 39 | 1.01 | 32 | 12 | 0.72 | 6 | 13 | 0.31 |
| 2 L - 1 | 1 | 12:54:00 | 6.89 | 1.69 | 47 | 55 | 1.56 | 48 | 25 | 1.22 | 14 | 20 | 0.55 |
| 2 L - 1 | 2 | 12:55:00 | 6.89 | 1.69 | 46 | 55 | 1.56 | 48 | 26 | 1.23 | 14 | 20 | 0.55 |
| 2 L - 1 | 4 | 12:57:00 | 6.89 | 1.69 | 47 | 55 | 1.56 | 48 | 26 | 1.23 | 14 | 20 | 0.56 |
| 2 L - 2 | 1 | 12:58:30 | 10.34 | 2.51 | 68 | 75 | 2.19 | 67 | 42 | 1.81 | 23 | 28 | 0.85 |
| 2 L - 2 | 2 | 12:59:30 | 10.34 | 2.51 | 69 | 75 | 2.21 | 68 | 42 | 1.83 | 24 | 29 | 0.87 |
| 2 L - 2 | 4 | 13:01:30 | 10.34 | 2.51 | 69 | 75 | 2.21 | 68 | 42 | 1.83 | 24 | 28 | 0.87 |
| 2 L - 3 | 1 | 13:03:00 | 13.79 | 3.32 | 90 | 95 | 2.84 | 88 | 58 | 2.42 | 33 | 37 | 1.16 |
| 2 L - 3 | 2 | 13:04:00 | 13.79 | 3.32 | 91 | 95 | 2.86 | 88 | 58 | 2.43 | 33 | 37 | 1.17 |
| 2 L - 3 | 4 | 13:06:00 | 13.79 | 3.32 | 92 | 96 | 2.88 | 89 | 59 | 2.45 | 34 | 37 | 1.17 |
| 2 L - 3 | 8 | 13:10:00 | 13.79 | 3.32 | 92 | 96 | 2.88 | 89 | 60 | 2.46 | 34 | 37 | 1.18 |
| 2 U - 1 | 1 | 13:11:30 | 6.89 | 1.69 | 51 | 60 | 1.72 | 54 | 30 | 1.38 | 18 | 21 | 0.65 |
| 2 U - 1 | 2 | 13:12:30 | 6.89 | 1.69 | 51 | 60 | 1.70 | 53 | 29 | 1.37 | 18 | 21 | 0.64 |
| 2 U - 1 | 4 | 13:14:30 | 6.89 | 1.69 | 51 | 60 | 1.71 | 53 | 30 | 1.37 | 18 | 21 | 0.64 |
| 2 U - 2 | 1 | 13:16:00 | 3.45 | 0.88 | 29 | 40 | 1.05 | 33 | 14 | 0.77 | 8 | 12 | 0.34 |
| 2 U - 2 | 2 | 13:17:00 | 3.45 | 0.88 | 28 | 39 | 1.04 | 32 | 14 | 0.76 | 8 | 12 | 0.33 |
| 2 U - 2 | 4 | 13:19:00 | 3.45 | 0.88 | 28 | 39 | 1.03 | 32 | 14 | 0.75 | 8 | 12 | 0.33 |
| 2 U - 3 | 1 | 13:20:30 | 0.00 | 0.00 | 2 | 13 | 0.23 | 6 | -4 | 0.03 | -3 | 1 | -0.03 |
| 2 U - 3 | 2 | 13:21:30 | 0.00 | 0.00 | 1 | 13 | 0.21 | 5 | -4 | 0.02 | -3 | 1 | -0.04 |
| 2 U - 3 | 4 | 13:23:30 | 0.00 | 0.00 | 1 | 12 | 0.20 | 5 | -4 | 0.01 | -3 | 0 | -0.04 |
| 2 U - 3 | 8 | 13:27:30 | 0.00 | 0.00 | 1 | 12 | 0.19 | 4 | -5 | -0.01 | -3 | 0 | -0.05 |

# APPENDIX B

## O-CELL™ AND INSTRUMENTATION CALIBRATION SHEETS

# GRAPH of CALIBRATION DATA
(ENGLISH UNITS)
**1024-15 CALIBRATED ON 11/28/01**




| STROKE: | 1 INCH | 3 INCH | 5 INCH |
|---|---|---|---|
| PRESSURE PSI | LOAD KIPS | LOAD KIPS | LOAD KIPS |
| 0 | 0 | 0 | 0 |
| 600 | 227 | 224 | 221 |
| 1200 | 453 | 449 | 447 |
| 1800 | 674 | 669 | 670 |
| 2400 | 899 | 895 | 894 |
| 3000 | 1119 | 1115 | 1114 |
| 3600 | 1342 | 1334 | 1334 |
| 4200 | 1560 | 1555 | 1550 |
| 4800 | 1782 | 1777 | 1769 |
| 5400 | 2002 | 1997 | 1987 |
| 6000 | 2219 | 2213 | 2202 |
| 6600 | 2438 | 2433 | 2420 |
| 7200 | 2657 | 2650 | 2640 |
| 7800 | 2870 | 2861 | 2855 |
| 8400 | 3085 | 3076 | 3070 |

**26" O-CELL, SERIAL # 1024-15**

**LOAD CONVERSION FORMULA**

**LOAD = PRESSURE * 0.3666 + ( 13.6 )**
**{KIPS} {PSI}**

**Regression Output:**

| | |
|---|---|
| Constant | 13.641 |
| X Coefficient | 0.367 |
| R Squared | 1.000 |
| No. of Observations | 42 |
| Degrees of Freedom | 40 |
| Std Err of Y Est | 12.453 |
| Std Err of X Coef. | 0.001 |

CALIBRATION STANDARDS:

All data presented is derived from 6" dia. certified hydraulic pressure gauges and electronic load transducer, manufactured and calibrated by the University of Illinois at Champaign, Illinois. All calibrations and certifications are traceable through the Laboratory Master Deadweight Gauges directly to the National Institute of Standards and Technology. No Specific guidelines exist for calibration of load test jacks and equipment but procedures comply with similar guidelines for calibration of gauges, ANSI specifications B40.1.

| | |
|---|---|
| *AE & FC CUSTOMER: LOADTEST INC. | *CONTRACTOR: LONGFELLOW DRILLING |
| *AE & FC JOB NO.: 2957 | *JOB LOCATION: CLEARFIELD, IA |
| *CUSTOMER P.O.NO.: LT-8756 | *DATED: 03/04/02 |

SERVICE ENGINEER: [signature] DATE: 7 Mar 2002

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

# Vibrating Wire Displacement Transducer Calibration Report

Model Number: 4450-3-6

Range: 6"

Serial Number: 20686

Mfg. Number: 02-493

Customer: Loadtest Inc.

Temperature: 23.9 °C

Cust. I.D. #: n/a

Cal. Std. Control Numbers: 216, 124, 405, 524, 529

Job Number: 18442

Calibration Date: February 20, 2002

Technician: KDB

| Displacement (inches) | GK-401 Reading Position B Cycle 1 | Cycle 2 | Average | Change | % Linearity |
|---|---|---|---|---|---|
| 0.000 | 2514 | 2512 | 2513 | | -0.25 |
| 1.200 | 3774 | 3775 | 3775 | 1262 | 0.10 |
| 2.400 | 5021 | 5022 | 5022 | 1247 | 0.21 |
| 3.600 | 6257 | 6254 | 6256 | 1234 | 0.12 |
| 4.800 | 7488 | 7487 | 7488 | 1232 | -0.01 |
| 6.000 | 8715 | 8719 | 8717 | 1230 | -0.17 |

**Calibration Factor (C): 0.0009679 (Inches/ Digit)**

**Regression Zero: 2529**

**Refer to manual for temperature correction information.**

Function Test at Shipment (GK-401 Reading)

Position "B": 5534

or

Position "F":

Date: March 15, 2002

Temperature: 22.2 °C

Wiring Code: Red and Black: Gage White and Green: Thermistor

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

**GEOKON** 48 Spencer St. Lebanon, N.H. 03766 USA

# Vibrating Wire Displacement Transducer Calibration Report

Model Number: 4450-3-6

Range: 6"

Serial Number: 20687

Mfg. Number: 02-494

Customer: Loadtest Inc.

Temperature: 23.9 °C

Cust. I.D. #: n/a

Cal. Std. Control Numbers: 216, 124, 405, 524, 529

Job Number: 18442

Calibration Date: February 20, 2002

Technician: KDB

| Displacement (inches) | GK-401 Reading Position B Cycle 1 | Cycle 2 | Average | Change | % Linearity |
|---|---|---|---|---|---|
| 0.000 | 2489 | 2489 | 2489 | | -0.23 |
| 1.200 | 3755 | 3754 | 3755 | 1266 | 0.08 |
| 2.400 | 5008 | 5008 | 5008 | 1254 | 0.20 |
| 3.600 | 6250 | 6247 | 6249 | 1241 | 0.11 |
| 4.800 | 7490 | 7485 | 7488 | 1239 | -0.01 |
| 6.000 | 8724 | 8726 | 8725 | 1238 | -0.15 |

**Calibration Factor (C): 0.0009629 (Inches/ Digit)**

**Regression Zero: 2503**

**Refer to manual for temperature correction information.**

Function Test at Shipment (GK-401 Reading)

Position "B": 5540

or

Position "F": 

Date: March 15, 2002

Temperature: 21.9 °C

Wiring Code: Red and Black: Gage White and Green: Thermistor

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

# Vibrating Wire Displacement Transducer Calibration Report

Model Number: 4450-3-6

Range: 6"

Serial Number: 20688

Mfg. Number: 02-495

Customer: Loadtest Inc.

Temperature: 23.9 °C

Cust. I.D. #: n/a

Cal. Std. Control Numbers: 216, 124, 405, 524, 529

Job Number: 18442

Calibration Date: February 20, 2002

Technician: KOB

| Displacement (inches) | GK-401 Reading Position B Cycle 1 | Cycle 2 | Average | Change | % Linearity |
|---|---|---|---|---|---|
| 0.000 | 2468 | 2462 | 2465 | | -0.19 |
| 1.200 | 3721 | 3718 | 3720 | 1255 | 0.11 |
| 2.400 | 4958 | 4957 | 4958 | 1238 | 0.15 |
| 3.600 | 6184 | 6183 | 6184 | 1226 | 0.00 |
| 4.800 | 7422 | 7425 | 7424 | 1240 | 0.07 |
| 6.000 | 8648 | 8645 | 8647 | 1223 | -0.14 |

**Calibration Factor (C): 0.0009712 (Inches/ Digit)**

**Regression Zero: 2477**

**Refer to manual for temperature correction information.**

Function Test at Shipment (GK-401 Reading)

Position "B": 5485

or

Position "F": 

Date: March 15, 2002

Temperature: 21.9 °C

Wiring Code: Red and Black: Gage White and Green: Thermistor

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

# Sister Bar Calibration Report

Model Number : 4911-4

Serial Number: 23044

Customer: Loadtest Inc.

Job Number: 18442

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 23.4 °C

Calibration Date: March 14, 2002

Cal. Std. Control Numbers: 85888-1, 25167

Cable Length: 90 ft.

Factory Zero Reading: 6774

Regression Zero: 6796

Technician: KDB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 6851 | 6845 | 6848 | | |
| 1,500 | 7532 | 7531 | 7532 | 684 | -0.12 |
| 3,000 | 8272 | 8271 | 8272 | 740 | -0.09 |
| 4,500 | 9019 | 9024 | 9022 | 750 | 0.28 |
| 6,000 | 9756 | 9742 | 9749 | 728 | -0.11 |
| 100 | 6850 | | | | |

*For conversion factor, load to strain, refer to table C-2 of the Installation Manual.*

**Gage Factor:**

**0.344 Microstrain/Digit (GK-401 Pos."B")**

**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

**Users are advised to establish their own zero conditions.**

Linearity: ((Calculated Load-Applied Load)/ Max.Applied Load) X 100 percent
The above instrument was found to be In Tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

**GEOKON** 48 Spencer St. Lebanon, N.H. 03766 USA

# Sister Bar Calibration Report

Model Number : 4911-4

Serial Number: 23045

Customer: Loadtest Inc.

Job Number: 18442

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 23.3 °C

Calibration Date: March 14, 2002

Cal. Std. Control Numbers: 85888-1, 25167

Cable Length: 90 ft.

Factory Zero Reading: 7091

Regression Zero: 7124

Technician: KDB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 7179 | 7171 | 7175 | | |
| 1,500 | 7856 | 7851 | 7854 | 679 | -0.21 |
| 3,000 | 8602 | 8598 | 8600 | 747 | 0.16 |
| 4,500 | 9339 | 9330 | 9335 | 735 | 0.12 |
| 6,000 | 10070 | 10057 | 10064 | 729 | -0.10 |
| 100 | 7173 | | | | |

*For conversion factor, load to strain, refer to table C-2 of the Installation Manual.*

**Gage Factor:**

**0.345 Microstrain/Digit (GK-401 Pos."B")**

**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

**Users are advised to establish their own zero conditions.**

Linearity: ((Calculated Load-Applied Load)/ Max.Applied Load) X 100 percent

The above instrument was found to be In Tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

# Sister Bar Calibration Report

Model Number : 4911-4

Serial Number: 23048

Customer: Loadtest Inc.

Job Number: 18442

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 23.4 °C

Calibration Date: March 14, 2002

Cal. Std. Control Numbers: 85888-1, 25167

Cable Length: 80 ft.

Factory Zero Reading: 7084

Regression Zero: 7104

Technician: KDB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 7151 | 7148 | 7150 | | |
| 1,500 | 7831 | 7834 | 7833 | 683 | -0.04 |
| 3,000 | 8566 | 8573 | 8570 | 737 | 0.21 |
| 4,500 | 9297 | 9301 | 9299 | 730 | 0.20 |
| 6,000 | 10012 | 10020 | 10016 | 717 | -0.23 |
| 100 | 7148 | | | | |

*For conversion factor, load to strain, refer to table C-2 of the Installation Manual.*

**Gage Factor:**

**0.347 Microstrain/Digit (GK-401 Pos."B")**

**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

**Users are advised to establish their own zero conditions.**

Linearity: ((Calculated Load-Applied Load)/ Max.Applied Load) X 100 percent

The above instrument was found to be In Tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

**GEOKON** 48 Spencer St. Lebanon, N.H. 03766 USA

# Sister Bar Calibration Report

Model Number : 4911-4

Serial Number: 23049

Customer: Loadtest Inc.

Job Number: 18442

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 23.6 °C

Calibration Date: March 14, 2002

Cal. Std. Control Numbers: 85888-1, 25167

Cable Length: 80 ft.

Factory Zero Reading: 7048

Regression Zero: 7066

Technician: KOB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 7111 | 7112 | 7112 | | |
| 1,500 | 7791 | 7786 | 7789 | 677 | 0.13 |
| 3,000 | 8513 | 8501 | 8507 | 719 | 0.12 |
| 4,500 | 9223 | 9225 | 9224 | 717 | 0.05 |
| 6,000 | 9943 | 9937 | 9940 | 716 | -0.04 |
| 100 | 7115 | | | | |

*For conversion factor, load to strain, refer to table C-2 of the Installation Manual.*

**Gage Factor:**

**0.351 Microstrain/Digit (GK-401 Pos."B")**

**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

**Users are advised to establish their own zero conditions.**

Linearity: ((Calculated Load-Applied Load)/ Max.Applied Load) X 100 percent

The above instrument was found to be In Tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

# Sister Bar Calibration Report

Model Number : 4911-4

Serial Number: 23052

Customer: Loadtest Inc.

Job Number: 18442

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 23.5 °C

Calibration Date: March 14, 2002

Cal. Std. Control Numbers: 85888-1, 25167

Cable Length: 70 ft.

Factory Zero Reading: 7113

Regression Zero: 7133

Technician: KOB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 7182 | 7174 | 7178 | | |
| 1,500 | 7875 | 7877 | 7876 | 698 | 0.02 |
| 3,000 | 8620 | 8626 | 8623 | 747 | 0.17 |
| 4,500 | 9369 | 9367 | 9368 | 745 | 0.25 |
| 6,000 | 10095 | 10095 | 10095 | 727 | -0.27 |
| 100 | 7176 | | | | |

*For conversion factor, load to strain, refer to table C-2 of the Installation Manual.*

**Gage Factor:**

**0.343 Microstrain/Digit (GK-401 Pos."B")**

**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

**Users are advised to establish their own zero conditions.**

Linearity: ((Calculated Load-Applied Load)/ Max.Applied Load) X 100 percent

The above instrument was found to be In Tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

# Sister Bar Calibration Report

Model Number : 4911-4

Serial Number: 23053

Customer: Loadtest Inc.

Job Number: 18442

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 23.7 °C

Calibration Date: March 14, 2002

Cal. Std. Control Numbers: 85888-1, 25167

Cable Length: 70 ft.

Factory Zero Reading: 7062

Regression Zero: 7076

Technician: KDB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 7127 | 7126 | 7127 | | |
| 1,500 | 7801 | 7794 | 7798 | 671 | -0.26 |
| 3,000 | 8539 | 8535 | 8537 | 740 | 0.09 |
| 4,500 | 9277 | 9277 | 9277 | 740 | 0.46 |
| 6,000 | 9984 | 9984 | 9984 | 707 | -0.31 |
| 100 | 7128 | | | | |

*For conversion factor, load to strain, refer to table C-2 of the Installation Manual.*

**Gage Factor:**

**0.347 Microstrain/Digit (GK-401 Pos."B")**

**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

**Users are advised to establish their own zero conditions.**

Linearity: ((Calculated Load-Applied Load)/ Max.Applied Load) X 100 percent

The above instrument was found to be In Tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

# APPENDIX C

## CONSTRUCTION OF THE EQUIVALENT TOP-LOADED LOAD-SETTLEMENT CURVE

# CONSTRUCTION OF THE EQUIVALENT TOP-LOADED LOAD-SETTLEMENT CURVE FROM THE RESULTS OF AN O-CELL™ TEST (August, 2000)

**Introduction:** Some engineers find it useful to see the results of an O-cell™ load test in the form of a curve showing the load versus settlement of a top-loaded driven or bored pile (drilled shaft). We believe that an O-cell™ test can provide a good estimate of this curve when using the method described herein.

**Assumptions:** We make the following assumptions, which we consider both reasonable and usually conservative:

1. The end bearing load-movement curve in a top-loaded shaft has the same loads for a given movement as the net (subtract buoyant weight of pile above O-cell™) end bearing load-movement curve developed by the bottom of the O-cell™ when placed at or near the bottom of the shaft.

2. The side shear load-movement curve in a top-loaded shaft has the same net shear, multiplied by an adjustment factor 'F', for a given downward movement as occurred in the O-cell™ test for that same movement at the top of the cell in the upward direction. The same applies to the upward movement in a top-loaded tension test. Unless noted otherwise, we use the following adjustment factors: (a) F = 1.00 in all rock sockets and for primarily cohesive soils in compression (b) F = 0.95 in primarily cohesionless soils (c) F = 0.80 for all soils in top load tension tests.

3. We initially assume the pile behaves as a rigid body, but include the elastic compressions that are part of the movement data obtained from an O-cell™ test (OLT). Using this assumption, we construct an equivalent top-load test (TLT) movement curve by the method described below in Procedure Part I. We then use the following Procedure Part II to correct for the effects of the additional elastic compressions in a TLT.

4. Consider the case with the O-cell™, or the bottom O-cell™ of more than one level of cells, placed some distance above the bottom of the shaft. We assume the part of the shaft below the cell, now top-loaded, has the same load-movement behavior as when top-loading the entire shaft. For this case the subsequent "end bearing movement curve" refers to the movement of the entire length of shaft below the cell

**Procedure Part I:** Please refer to the attached Figure A showing O-cell™ test results and to Figure B, the constructed equivalent top loaded settlement curve. Note that each of the curves shown has points numbered from 1 to 12 such that the same point number on each curve has the same magnitude of movement. For example, point 4 has an upward and downward movement of 0.40 inches in Figure A and the same 0.40 inches downward in Figure B.

Note: This report shows the O-cell movement data in a Figure similar to Fig. A, but uses the gross loads as obtained in the field. Fig. A uses net loads to make it easier for the reader to convert Fig. A into Fig. B without the complication of the first converting gross to net loads. For our conservative reconstruction of the top loaded settlement curve we first convert both of the O-cell components to net load.

Using the above assumptions, construct the equivalent curve as follows: Select an arbitrary movement such as the 0.40 inches to give point 4 on the shaft side shear load movement curve in Figure A and record the 2,090 ton load in shear at that movement. Because we have initially assumed a rigid pile, the top of pile moves downward the same as the bottom. Therefore, find point 4 with 0.40 inches of upward movement on the end bearing load movement curve and record the corresponding load of 1,060 tons. Adding these two loads will give the total load of 3,150 tons due to side shear plus end bearing at the same movement and thus gives point 4 on the Figure B load settlement curve for an equivalent top-loaded test.

One can use the above procedure to obtain all the points in Figure B up to the component that moved the least at the end of the test, in this case point 5 in side shear. To take advantage of the fact that the test produced end bearing movement data up to point 12, we need to make an extrapolation of the side shear curve. We usually use a convenient and suitable hyperbolic curve fitting technique for this extrapolation. Deciding on the maximum number of data points to provide a good fit (a high $r^2$ correlation coefficient) requires some judgment. In this case we omitted point 1 to give an $r^2 = 0.999$ (including point 1 gave an $r^2 = 0.966$) with the result shown as points 6 to 12 on the dotted extension of the measured side shear curve. Using the same movement matching procedure described earlier we can then extend the equivalent curve to points 6 to 12. The results, shown in Figure B as a dashed line, signify that this part of the equivalent curve depends partly on extrapolated data.

Sometimes, if the data warrants, we will use extrapolations of both side shear and end bearing to extend the equivalent curve to a greater movement than the maximum measured (point 12). An appendix in this report gives the details of the extrapolation(s) used with the present O-cell™ test and shows the fit with the actual data.

**Procedure Part II**: The elastic compression in the equivalent top load test always exceeds that in the O-cell™ test. It not only produces more top movement, but also additional side shear movement, which then generates more side shear, which produces more compression, etc . . . An exact solution of this load transfer problem requires knowing the side shear vs. vertical movement (t-y) curves for a large number of pile length increments and solving the resulting set of simultaneous equations or using finite element or finite difference simulations to obtain an approximate solution for these equations. We usually do not have the data to obtain the many accurate t-y curves required. Fortunately, the approximate solution described below usually suffices.

The attached analysis p. 6 gives the equations for the elastic compressions that occur in the OLT with one or two levels of O-cells™. Analysis p. 7 gives the equations for the elastic compressions that occur in the equivalent TLT. Both sets of equations do not include the elastic compression below the O-cell™ because the same compression takes place in both the OLT and the TLT. This is equivalent to taking $l_3 = 0$. Subtracting the OLT from the TLT compression gives the desired additional elastic compression at the top of the TLT. We then add the additional elastic compression to the 'rigid' equivalent curve obtained from Part I to obtain the final, corrected equivalent load-settlement curve for the TLT on the same pile as the actual OLT.

Note that the above pp. 6 and 7 give equations for each of three assumed patterns of developed side shear stress along the pile. The pattern shown in the center of the three applies to any approximately determined side shear distribution. Experience has shown the initial solution for the additional elastic compression, as described above, gives an adequate and slightly conservative (high) estimate of the additional compression versus more sophisticated load-transfer analyses as described in the first paragraph of this Part II.

The analysis p. 8 provides an example of calculated results in English units on a hypothetical 1-stage, single level OLT using the simplified method in Part II with the centriod of the side shear distribution 44.1% above the base of the O-cell™. Figure C compares the corrected with the rigid curve of Figure B. Page 9 contains an example equivalent to that above in SI units.

The final analysis p. 10 provides an example of calculated results in English units on a hypothetical 3-stage, multi level OLT using the simplified method in Part II with the centriod of the combined upper and middle side shear distribution 44.1% above the base of the bottom O-cell™. The individual centroids of the upper and middle side shear distributions lie 39.6% and 57.9% above and below the middle O-cell™, respectively. Figure E compares the corrected with the rigid curve. Page 11 contains an example equivalent to that above in SI units.

**Other Tests:** The example illustrated in Figure A has the maximum component movement in end bearing. The procedures remain the same if the maximum test movement occurred in side shear. Then we would have extrapolated end bearing to produce the dashed-line part of the reconstructed top-load settlement curve.

The example illustrated also assumes a pile top-loaded in compression. For a pile top-loaded in tension we would, based on Assumptions 2. and 3., use the upward side shear load curve in Figure A, multiplied by the F = 0.80 noted in Assumption 2., for the equivalent top-loaded displacement curve.

**Expected Accuracy:** We know of only five series of tests that provide the data needed to make a direct comparison between actual, full scale, top-loaded pile movement behavior and the equivalent behavior obtained from an O-cell™ test by the method described herein. These involve three sites in Japan and one in Singapore, in a variety of soils, with three compression tests on bored piles (drilled shafts), 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 a 37 m length. The driven pile had a 1-m increment modular construction and a 9 m length. The largest top loading = 28 MN (3,150 tons).

The following references detail the aforementioned Japanese tests and the results therefrom:

> Kishida H. et al., 1992, "Pile Loading Tests at Osaka Amenity Park Project," Paper by Mitsubishi Co., also briefly described in Schmertmann (1993, see bibliography). Compares one drilled shaft in tension and another in compression.
>
> Ogura, H. et al., 1995, "Application of Pile Toe Load Test to Cast-in-place Concrete Pile and Precast Pile," special volume 'Tsuchi-to-Kiso' on Pile Loading Test, Japanese Geotechnical Society, Vol. 3, No. 5, Ser. No. 448. Original in Japanese. Translated by M. B. Karkee, GEOTOP Corporation. Compares one drilled shaft and one driven pile, both in compression.

We compared the predicted equivalent and measured top load at three top movements in each of the above four Japanese comparisons. The top movements ranged from ¼ inch (6 mm) to 40 mm, depending on the data available. The (equiv./meas.) ratios of the top load averaged 1.03 in the 15 comparisons with a coefficient of variation of less than 10%. We believe that these available comparisons help support the practical validity of the equivalent top load method described herein.

L. S. Peng, A. M. Koon, R. Page and C. W. Lee report the results of a class-A prediction by others of the TLT curve from an Osterberg cell test on a 1.2 m diameter, 37.2 m long bored pile in Singapore, compared to an adjacent pile with the same dimensions actually top-loaded by kentledge. They report about a 4% difference in ultimate capacity and less than 8% difference in settlements over the 1.0 to 1.5 times working load range -- comparable to the accuracy noted above. Their paper has the title "OSTERBERG CELL TESTING OF PILES", and was published in March 1999 in the Proceedings of the International Conference on Rail Transit, held in Singapore and published by the Association of Consulting Engineers Singapore.

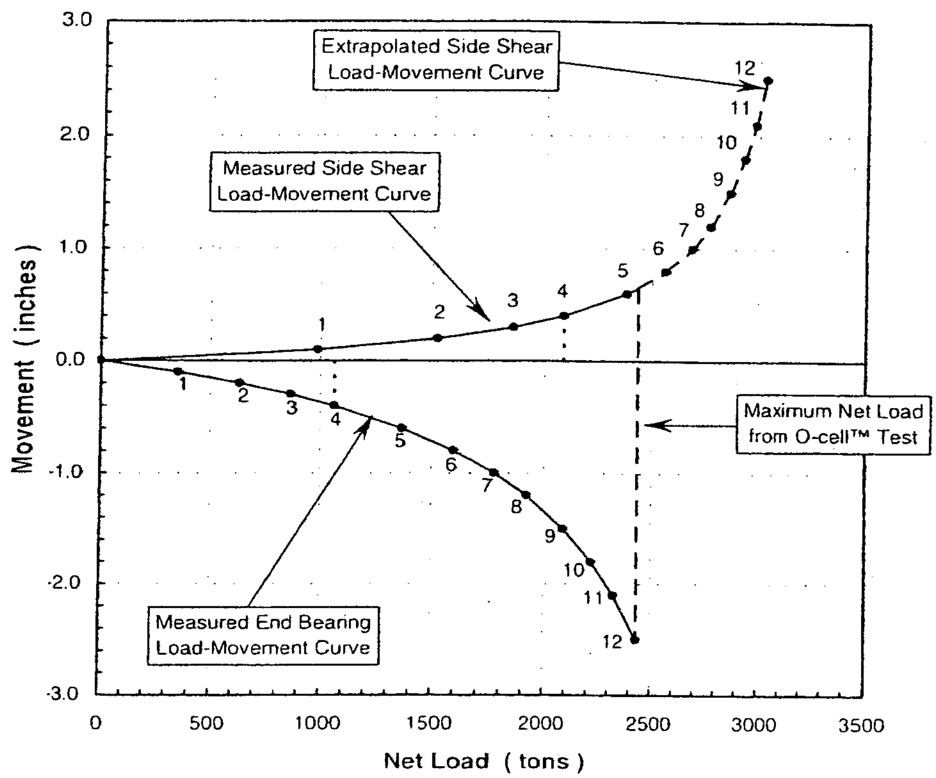
B. H. Fellenius has made several finite element method (FEM) studies of an OLT in which he adjusted the parameters to produce good load-deflection matches with the OLT up and down load-deflection curves. He then used the same parameters to predict the TLT deflection curve. We compared the FEM-predicted curve with the equivalent load-deflection predicted by the previously described Part I and II procedures, with the results again comparable to the accuracy noted above. The ASCE has published a paper by Fellenius et. al. titled "O-Cell Testing and FE Analysis of 28-m-Deep Barrette in Manila, Philippines" in the Journal of Geotechnical and Geoenvironmental Engineering, Vol. 125, No. 7, July 1999, p. 566. It details one of his comparison studies.

<u>Limitations</u>: The engineer using these results should judge the conservatism, or lack thereof, of the aforementioned assumptions and extrapolation(s) before utilizing the results for design purposes. For example, brittle failure behavior may produce movement curves with abrupt changes in curvature (not hyperbolic). However, we believe the hyperbolic fit method and our assumptions used usually produce reasonable equivalent top load settlement curves.

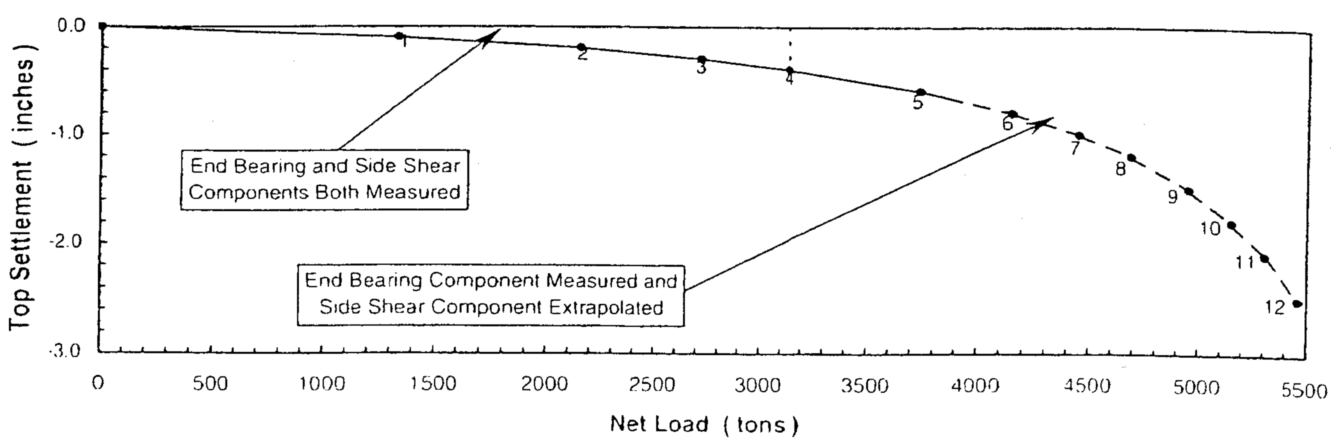
August, 2000

Example of the Construction of an Equivalent Top-Loaded Settlement Curve (Figure B) From Osterberg Cell Test Results (Figure A)

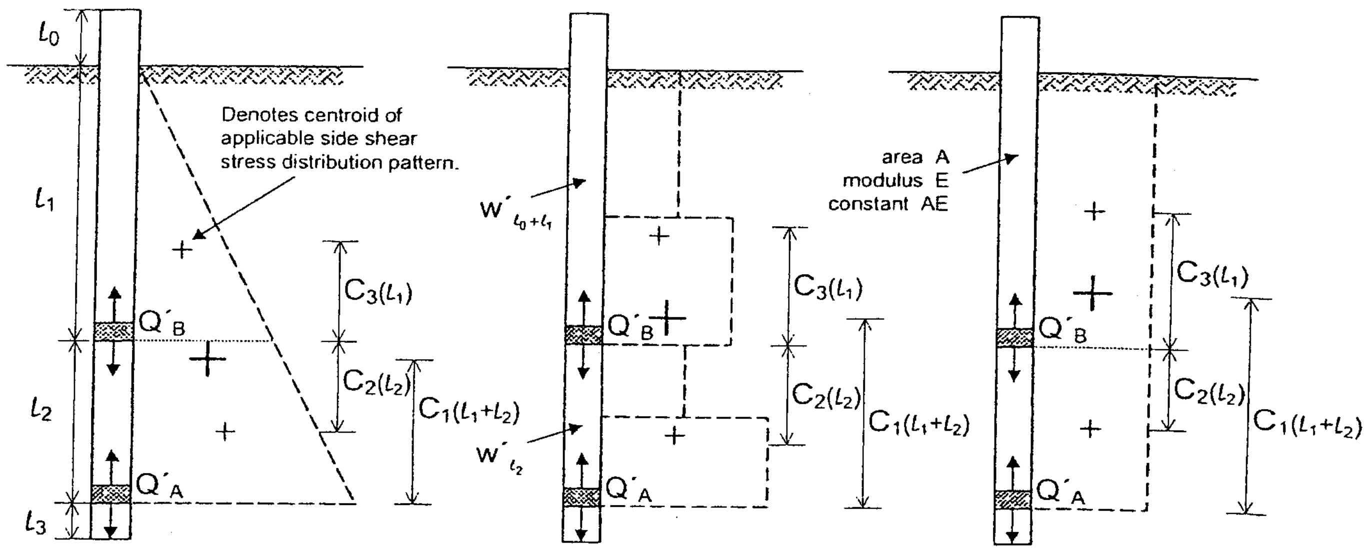
## Figure A




## Figure B



# Theoretical Elastic Compression in O-cell™ Test Based on Pattern of Developed Side Shear Stress




**1-Stage Single Level Test (Q´A only):** $\delta_{OLT} = \delta_{T(\ell_1+\ell_2)}$

| | | |
|---|---|---|
| $C_1 = \frac{1}{3}$ | Centroid Factor $= C_1$ | $C_1 = \frac{1}{2}$ |
| $\delta_{T(\ell_1+\ell_2)} = \frac{1}{3}\frac{Q'_{TA}(\ell_1+\ell_2)}{AE}$ | $\delta_{T(\ell_1+\ell_2)} = C_1\frac{Q'_{TA}(\ell_1+\ell_2)}{AE}$ | $\delta_{T(\ell_1+\ell_2)} = \frac{1}{2}\frac{Q'_{TA}(\ell_1+\ell_2)}{AE}$ |

**3-Stage Multi Level Test (Q´A and Q´B):** $\delta_{OLT} = \delta_{T\ell_1} + \delta_{\downarrow\ell_2}$

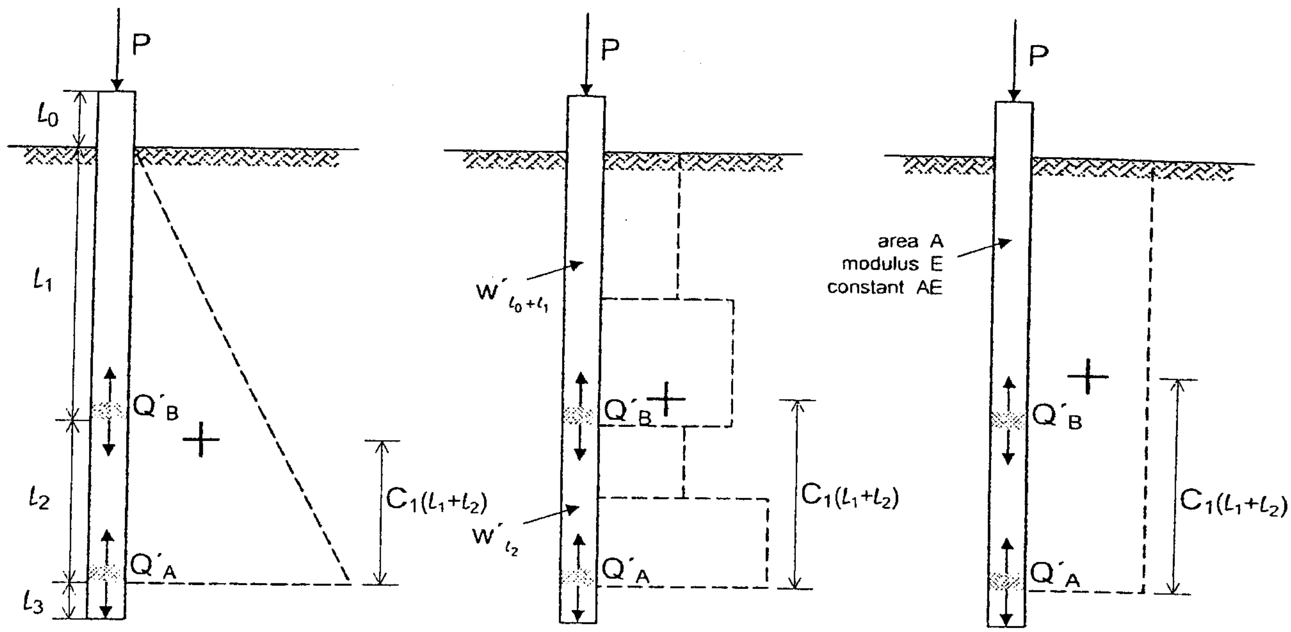
| | | |
|---|---|---|
| $C_3 = \frac{1}{3}$ | Centroid Factor $= C_3$ | $C_3 = \frac{1}{2}$ |
| $\delta_{T\ell_1} = \frac{1}{3}\frac{Q'_{TB}\ell_1}{AE}$ | $\delta_{T\ell_1} = C_3\frac{Q'_{TB}\ell_1}{AE}$ | $\delta_{T\ell_1} = \frac{1}{3}\frac{Q'_{TB}\ell_1}{AE}$ |
| $C_2 = \frac{1}{3}\left(\frac{3\ell_1+2\ell_2}{2\ell_1+\ell_2}\right)$ | Centroid Factor $= C_2$ | $C_2 = \frac{1}{2}$ |
| $\delta_{\downarrow\ell_2} = \frac{1}{3}\left(\frac{3\ell_1+2\ell_2}{2\ell_1+\ell_2}\right)\frac{Q'_{\downarrow B}\ell_2}{AE}$ | $\delta_{\downarrow\ell_2} = C_2\frac{Q'_{\downarrow B}\ell_2}{AE}$ | $\delta_{\downarrow\ell_2} = \frac{1}{2}\frac{Q'_{\downarrow B}\ell_2}{AE}$ |

Net Loads:

$Q'_{\uparrow A} = Q_{\uparrow A} - W'_{\ell_0+\ell_1+\ell_2}$ $\quad$ $Q'_{\uparrow B} = Q_{\uparrow B} - W'_{\ell_0+\ell_1}$ $\quad$ $Q'_{\downarrow B} = Q'_{\downarrow B} + W'_{\ell_2}$

W´ = pile weight, bouyant where below water table

# Theoretical Elastic Compression in Top Loaded Test Based on Pattern of Developed Side Shear Stress




**Top Loaded Test:** $\delta_{TLT} = \delta_{\downarrow\ell_0} + \delta_{\downarrow\ell_1+\ell_2}$

| | | |
|---|---|---|
| $\delta_{\downarrow\ell_0} = \dfrac{P\ell_0}{AE}$ | $\delta_{\downarrow\ell_0} = \dfrac{P\ell_0}{AE}$ | $\delta_{\downarrow\ell_0} = \dfrac{P\ell_0}{AE}$ |
| $C_1 = \dfrac{1}{3}$ | Centroid Factor $= C_1$ | $C_1 = \dfrac{1}{2}$ |
| $\delta_{\downarrow\ell_1+\ell_2} = \dfrac{(Q'_{\downarrow A}+2P)}{3}\dfrac{(\ell_2+\ell_2)}{AE}$ | $\delta_{\downarrow\ell_1+\ell_2} = [(C_1)Q'_{\downarrow A}+(1-C_1)P]\dfrac{(\ell_1+\ell_2)}{AE}$ | $\delta_{\downarrow\ell_1+\ell_2} = \dfrac{(Q'_{\downarrow A}+P)}{2}\dfrac{(\ell_1+\ell_2)}{AE}$ |

**Net and Equivalent Loads:**

$Q'_{\downarrow A} = Q_{\downarrow A} - W'_{\ell_0+\ell_1+\ell_2}$ $\quad P_{single} = Q'_{\downarrow A} + Q'_{\uparrow A}$ $\quad P_{multi} = Q'_{\downarrow A} + Q'_{\uparrow B} + Q'_{\downarrow B}$

Component loads Q selected at the same $(\pm)\,\Delta_{OLT}$.

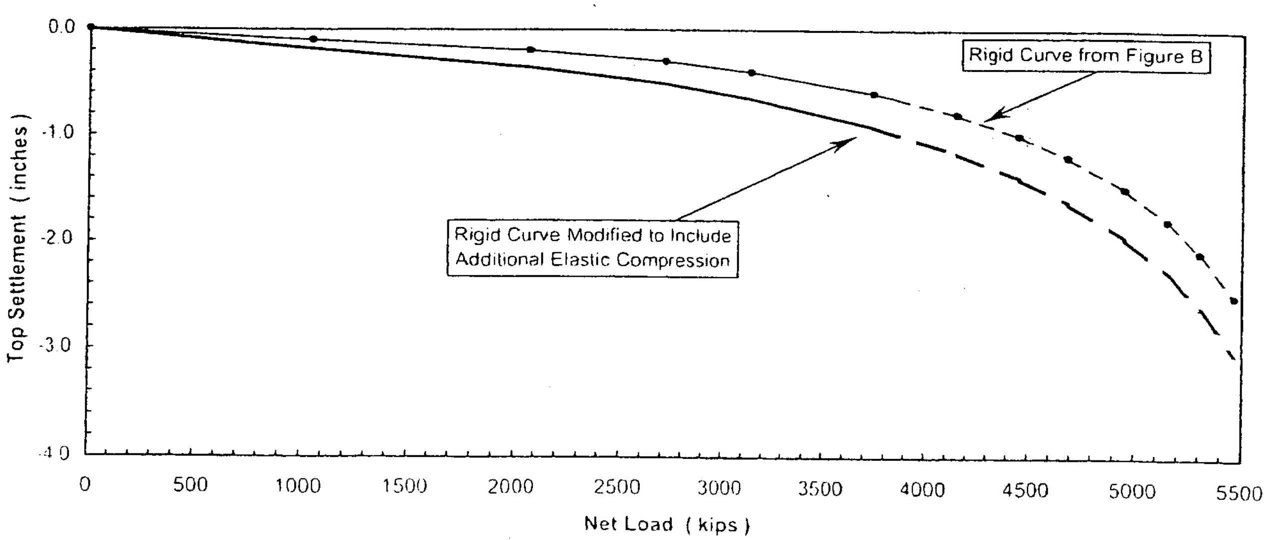
## Example Calcuation for the Additional Elastic Compression Correction for Single Level Test (English Units)

**Given:**

$C_1 =$ 0.441
$AE =$ 3820000 kips (assumed constant throughout test)
$\ell_0 =$ 5.9 ft
$\ell_1 =$ 48.2 ft (embedded length of shaft above O-cell™)
$\ell_2 =$ 0.0 ft
$\ell_3 =$ 0.0 ft
**Shear reduction factor** = 1.00 (cohesive soil)

| $\Delta_{OLT}$ (in) | $Q'_{\downarrow A}$ (kips) | $Q'_{\uparrow A}$ (kips) | P (kips) | $\delta_{TLT}$ (in) | $\delta_{OLT}$ (in) | $\Delta_\delta$ (in) | $\Delta_{OLT} + \Delta_\delta$ (in) |
|---|---|---|---|---|---|---|---|
| 0.000 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.100 | 352 | 706 | 1058 | 0.133 | 0.047 | 0.086 | 0.186 |
| 0.200 | 635 | 1445 | 2080 | 0.257 | 0.096 | 0.160 | 0.360 |
| 0.300 | 867 | 1858 | 2725 | 0.339 | 0.124 | 0.215 | 0.515 |
| 0.400 | 1061 | 2088 | 3149 | 0.396 | 0.139 | 0.256 | 0.656 |
| 0.600 | 1367 | 2382 | 3749 | 0.478 | 0.159 | 0.319 | 0.919 |
| 0.800 | 1597 | 2563 | 4160 | 0.536 | 0.171 | 0.365 | 1.165 |
| 1.000 | 1777 | 2685 | 4462 | 0.579 | 0.179 | 0.400 | 1.400 |
| 1.200 | 1921 | 2773 | 4694 | 0.613 | 0.185 | 0.427 | 1.627 |
| 1.500 | 2091 | 2867 | 4958 | 0.651 | 0.191 | 0.460 | 1.960 |
| 1.800 | 2221 | 2933 | 5155 | 0.680 | 0.196 | 0.484 | 2.284 |
| 2.100 | 2325 | 2983 | 5308 | 0.703 | 0.199 | 0.504 | 2.604 |
| 2.500 | 2434 | 3032 | 5466 | 0.726 | 0.202 | 0.524 | 3.024 |

### Figure C



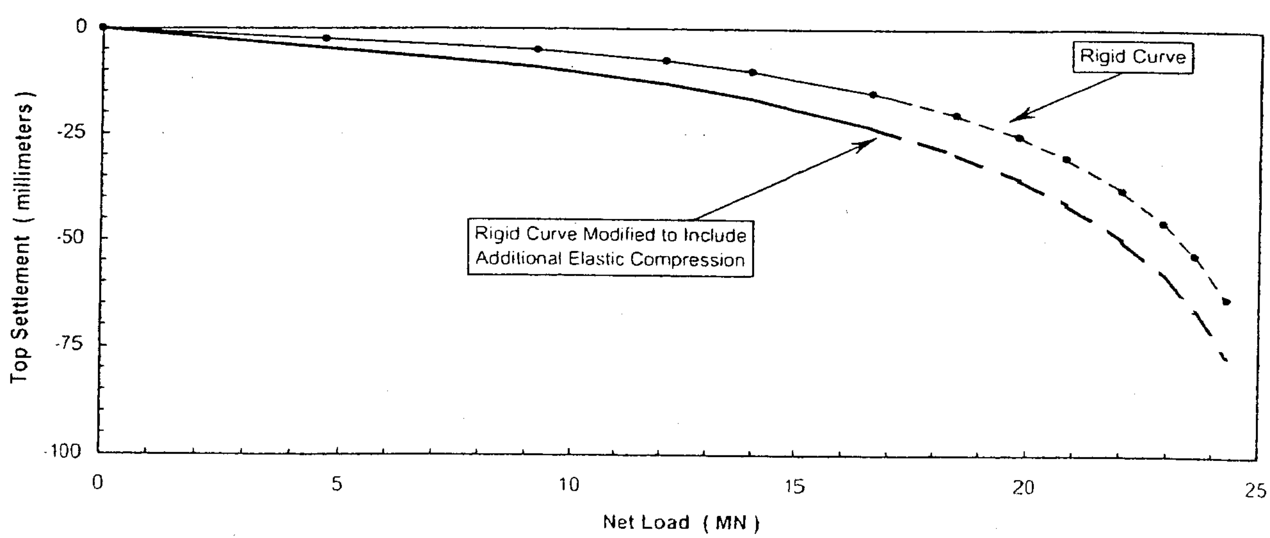
## Example Calcuation for the Additional Elastic Compression Correction for Single Level Test (SI Units)

**Given:**

$C_1$ = 0.441
AE = 17000 MN (assumed constant throughout test)
$\ell_0$ = 1.80 m
$\ell_1$ = 14.69 m (embedded length of shaft above O-cell™)
$\ell_2$ = 0.00 m
$\ell_3$ = 0.00 m
Shear reduction factor = 1.00 (cohesive soil)

| $\Delta_{OLT}$ (mm) | $Q'_{\downarrow A}$ (MN) | $Q'_{TA}$ (MN) | P (MN) | $\delta_{TLT}$ (mm) | $\delta_{OLT}$ (mm) | $\Delta_\delta$ (mm) | $\Delta_{OLT} + \Delta_\delta$ (mm) |
|---|---|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.54 | 1.57 | 3.14 | 4.71 | 3.37 | 1.20 | 2.17 | 4.71 |
| 5.08 | 2.82 | 6.43 | 9.25 | 6.52 | 2.45 | 4.07 | 9.15 |
| 7.62 | 3.86 | 8.27 | 12.12 | 8.61 | 3.15 | 5.46 | 13.08 |
| 10.16 | 4.72 | 9.29 | 14.01 | 10.05 | 3.54 | 6.51 | 16.67 |
| 15.24 | 6.08 | 10.60 | 16.68 | 12.14 | 4.04 | 8.10 | 23.34 |
| 20.32 | 7.11 | 11.40 | 18.50 | 13.60 | 4.34 | 9.26 | 29.58 |
| 25.40 | 7.90 | 11.94 | 19.85 | 14.70 | 4.55 | 10.15 | 35.55 |
| 30.48 | 8.55 | 12.33 | 20.88 | 15.55 | 4.70 | 10.85 | 41.33 |
| 38.10 | 9.30 | 12.75 | 22.05 | 16.53 | 4.86 | 11.67 | 49.77 |
| 45.72 | 9.88 | 13.05 | 22.93 | 17.27 | 4.97 | 12.29 | 58.01 |
| 53.34 | 10.34 | 13.27 | 23.61 | 17.84 | 5.06 | 12.79 | 66.13 |
| 63.50 | 10.83 | 13.48 | 24.31 | 18.44 | 5.14 | 13.30 | 76.80 |

**Figure D**



## Example Calcuation for the Additional Elastic Compression Correction for Multi Level Test (English Units)

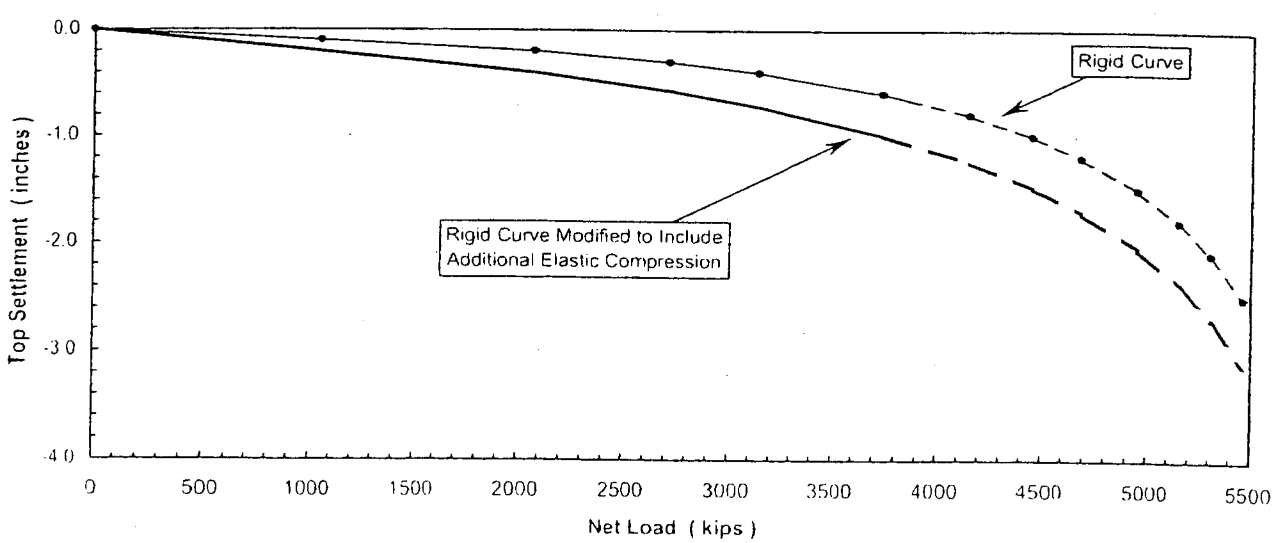
Given:

$C_1$ = 0.441
$C_2$ = 0.579
$C_3$ = 0.396
AE = 3820000 kips (assumed constant throughout test)
$\ell_0$ = 5.9 ft
$\ell_1$ = 30.0 ft (embedded length of shaft above mid-cell)
$\ell_2$ = 18.2 ft (embedded length of shaft between O-cells™)
$\ell_3$ = 0.0 ft

Shear reduction factor = 1.00 (cohesive soil)

| $\Delta_{OLT}$ (in) | $Q'_{\downarrow A}$ (kips) | $Q'_{\downarrow B}$ (kips) | $Q'_{\uparrow B}$ (kips) | P (kips) | $\delta_{TLT}$ (in) | $\delta_{OLT}$ (in) | $\Delta_\delta$ (in) | $\Delta_{OLT} + \Delta_\delta$ (in) |
|---|---|---|---|---|---|---|---|---|
| 0.000 | 0 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.100 | 352 | 247 | 459 | 1058 | 0.133 | 0.025 | 0.107 | 0.207 |
| 0.200 | 635 | 506 | 939 | 2080 | 0.257 | 0.052 | 0.205 | 0.405 |
| 0.300 | 867 | 650 | 1208 | 2725 | 0.339 | 0.067 | 0.272 | 0.572 |
| 0.400 | 1061 | 731 | 1357 | 3149 | 0.396 | 0.075 | 0.321 | 0.721 |
| 0.600 | 1367 | 834 | 1548 | 3749 | 0.478 | 0.085 | 0.393 | 0.993 |
| 0.800 | 1597 | 897 | 1666 | 4160 | 0.536 | 0.092 | 0.444 | 1.244 |
| 1.000 | 1777 | 940 | 1745 | 4462 | 0.579 | 0.096 | 0.483 | 1.483 |
| 1.200 | 1921 | 971 | 1802 | 4694 | 0.613 | 0.099 | 0.513 | 1.713 |
| 1.500 | 2091 | 1003 | 1864 | 4958 | 0.651 | 0.103 | 0.548 | 2.048 |
| 1.800 | 2221 | 1027 | 1907 | 5155 | 0.680 | 0.105 | 0.575 | 2.375 |
| 2.100 | 2325 | 1044 | 1939 | 5308 | 0.703 | 0.107 | 0.596 | 2.696 |
| 2.500 | 2434 | 1061 | 1971 | 5466 | 0.726 | 0.109 | 0.618 | 3.118 |

Figure E



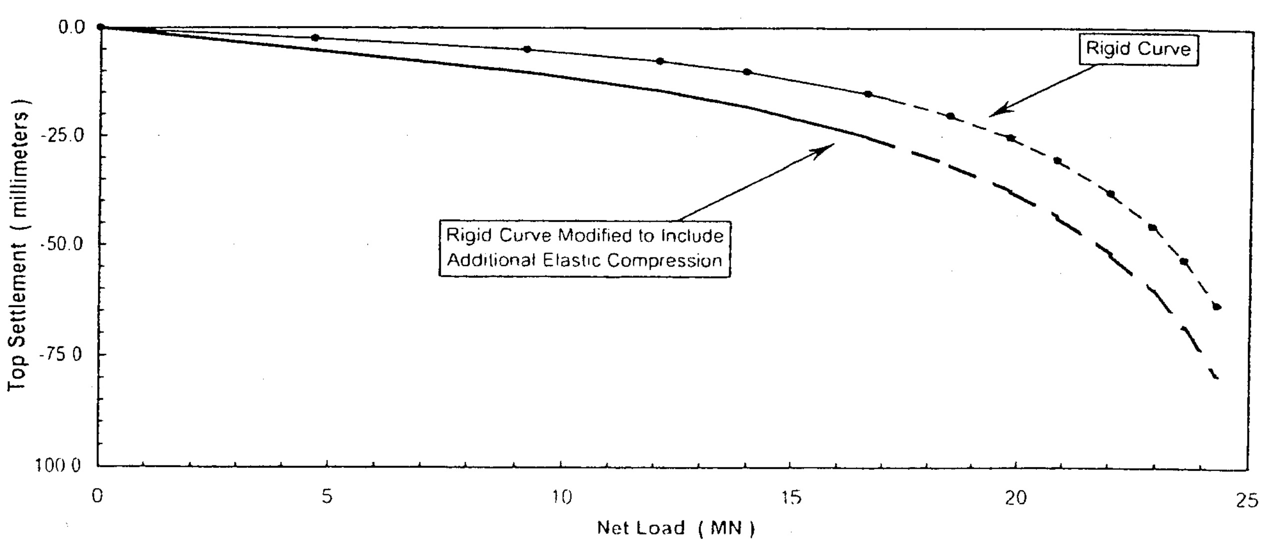
## Example Calcuation for the Additional Elastic Compression Correction for Multi Level Test (SI Units)

**Given:**

$C_1 =$ 0.441
$C_2 =$ 0.579
$C_3 =$ 0.396
AE = 17000 MN (assumed constant throughout test)
$\ell_0 =$ 1.80 m
$\ell_1 =$ 9.14 m (embedded length of shaft above mid-cell)
$\ell_2 =$ 5.55 m (embedded length of shaft between O-cells™)
$\ell_3 =$ 0.00 m
Shear reduction factor = 1.00 (cohesive soil)

| $\Delta_{OLT}$ (in) | $Q'_{\downarrow A}$ (kips) | $Q'_{\downarrow B}$ (kips) | $Q'_{\uparrow B}$ (kips) | P (kips) | $\delta_{TLT}$ (in) | $\delta_{OLT}$ (in) | $\Delta_\delta$ (in) | $\Delta_{OLT} + \Delta_\delta$ (in) |
|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.54 | 1.57 | 1.10 | 2.04 | 4.71 | 3.37 | 0.64 | 2.73 | 5.27 |
| 5.08 | 2.82 | 2.25 | 4.18 | 9.25 | 6.52 | 1.31 | 5.21 | 10.29 |
| 7.62 | 3.86 | 2.89 | 5.37 | 12.12 | 8.61 | 1.69 | 6.92 | 14.54 |
| 10.16 | 4.72 | 3.25 | 6.04 | 14.01 | 10.05 | 1.90 | 8.15 | 18.31 |
| 15.24 | 6.08 | 3.71 | 6.89 | 16.68 | 12.14 | 2.17 | 9.97 | 25.21 |
| 20.32 | 7.11 | 3.99 | 7.41 | 18.50 | 13.60 | 2.33 | 11.27 | 31.59 |
| 25.40 | 7.90 | 4.18 | 7.76 | 19.85 | 14.70 | 2.44 | 12.26 | 37.66 |
| 30.48 | 8.55 | 4.32 | 8.02 | 20.88 | 15.55 | 2.52 | 13.03 | 43.51 |
| 38.10 | 9.30 | 4.46 | 8.29 | 22.05 | 16.53 | 2.61 | 13.92 | 52.02 |
| 45.72 | 9.88 | 4.57 | 8.48 | 22.93 | 17.27 | 2.67 | 14.60 | 60.32 |
| 53.34 | 10.34 | 4.64 | 8.62 | 23.61 | 17.84 | 2.71 | 15.13 | 68.47 |
| 63.50 | 10.83 | 4.72 | 8.76 | 24.31 | 18.44 | 2.76 | 15.68 | 79.18 |

Figure F



# APPENDIX D

## O-CELL™ METHOD FOR DETERMINING CREEP LIMIT LOADING

## O-CELL METHOD FOR DETERMINING A CREEP LIMIT LOADING ON THE EQUIVALENT TOP-LOADED SHAFT

**Background:** O-cell testing provides a sometimes useful method for evaluating that load beyond which a top-loaded drilled shaft might experience significant unwanted creep behavior. We refer to this load as the "creep limit," also sometimes known as the "yield limit" or "yield load".

To our knowledge, Housel (1959) first proposed the method described below for determining the creep limit. Stoll (1961), Bourges and Levillian (1988), and Fellenius (1996) provide additional references. This method also follows from long experience with the pressuremeter test (PMT). Figure 8 and section 9.4 from ASTM D4719, reproduced below, show and describe the creep curve routinely determined from the PMT. The creep curve shows how the movement or strain obtained over a fixed time interval, 30 to 60 seconds, changes versus the applied pressure. One can often detect a distinct break in the curve at the pressure $P_e$ in Figure 8. Plastic deformations become significant beyond this break loading and progressively more severe creep can occur.

**Definition:** Similarly with O-cell testing using the ASTM Quick Method, one can conveniently measure the additional movement occurring over the final time interval at each constant load step, typically 2 to 4 minutes. A break in the curve of load vs. movement (as at $P_e$ with the PMT) indicates the creep limit.

We usually indicate such a creep limit in the O-cell test for either one, or both, of the side shear and end bearing components, and herein designate the corresponding movements as $M_{CL1}$ and $M_{CL2}$. We then combine the creep limit data to predict a creep limit load for the equivalent top loaded shaft.

**Procedure if both $M_{CL1}$ and $M_{CL2}$ available:** Creep cannot begin until the shaft movement exceeds the $M_{CL}$ values. A conservative approach would assume that creep begins when movements exceed the lesser of the $M_{CL}$ values. However, creep can occur freely only when the shaft has moved the greater of the two $M_{CL}$ values. Although less conservative, we believe the latter to match behavior better and therefore set the creep limit as that load on the equivalent top-loaded movement curve that matches the greater $M_{CL}$.

**Procedure if only $M_{CL1}$ available:** If we cannot determine a creep limit in the second component before it reaches its maximum movement $M_x$, we treat $M_x$ as $M_{CL2}$. From the above method one can say that the creep limit load exceeds, by some unknown amount, that obtained when using $M_{CL2} = M_x$.

**Procedure if no creep limit observed**: Then, according to the above, the creep limit for the equivalent top-loaded shaft will exceed, again by some unknown amount, that load on the equivalent curve that matches the movement of the component with the maximum movement.

**Limitations**: The accuracy in estimating creep limits depends, in part, on the scatter of the data in the creep limit plots. The more scatter, the more difficult to define a limit. The user should make his or her own interpretation if he or she intends to make important use of the creep limit interpretations. Sometimes we obtain excessive scatter of the data and do not attempt an interpretation for a creep limit and will indicate this in the report.

Excerpts from ASTM D4719
"Standard Test Method for Pressuremeter Testing in Soils"

9.4 For Procedure A, plot the volume increase readings ($V_{60}$) between the 30 s and 60 s reading on a separate graph. Generally, a part of the same graph is used, see Fig. 8. For Procedure B, plot the pressure decrease reading between the 30 s and 60 s reading on a separate graph. The test curve shows an almost straight line section within the range of either low volume increase readings ($V_{60}$) for Procedure A or low pressure decrease for Procedure B. In this range, a constant soil deformation modulus can be measured. Past the so-called creep pressure, plastic deformations become prevalent.

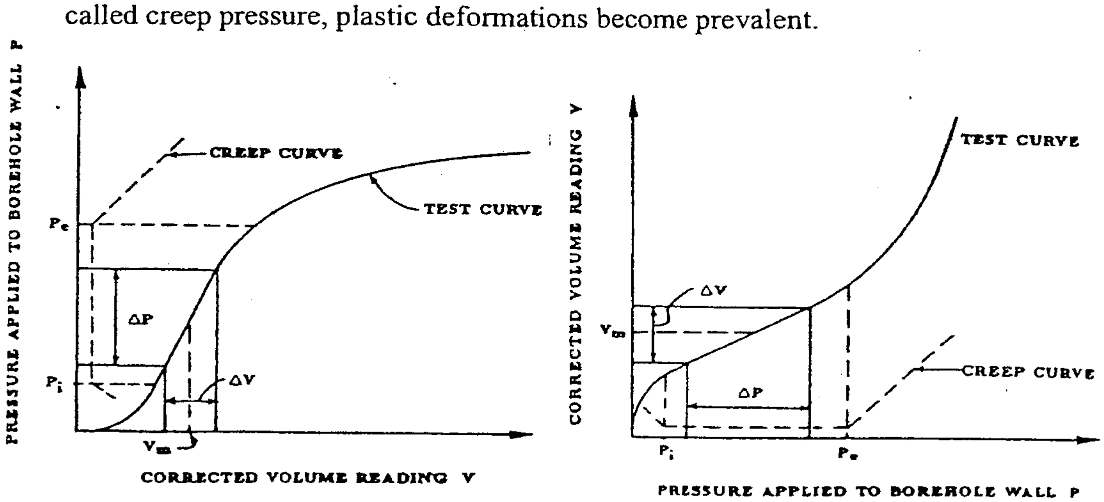



FIG. 8 Pressuremeter Test Curves for Procedure A

## References


Housel, W.S. (1959), "Dynamic & Static Resistance of Coshesive Soils" 1846-1959, ASTM STP 254, pp. 22-23.

Stoll, M.U.W. (1961, Discussion, Proc. 3rd ICSMFE, Paris, Vol. III, pp. 279-281.

Bourges, F. and Levillian, J-P (1988), "force portante des rideaux plans metalliques charges verticalmement," Bull. No. 158, Nov.-Dec., des laboratoires des ponts et chaussees, p. 24.

Fellenius, Bengt H. (1966), Basics of Foundation Design, BiTech Publishers Ltd., p.79.

# APPENDIX E

## SOIL BORING LOG

Form 610010M

METRIC

DATE MO DA YR 1 5/0/02

# Iowa Department of Transportation

Project Development
Office of Design (Soils)
Report of Bridge Soundings

JEFFERSON

APR 1 1 2002

CONSTR. RES.

| TEST HOLE NUMBER | STATION | ℄ ORDINATE LT CL RT | DIST | SURFACE ELEVATION | DEPTH TO WATER METERS | LOG OF HOLE TO METERS | DESCRIPTION OF MATERIAL | JOB NO. | CARD NUMBER |
|---|---|---|---|---|---|---|---|---|---|
| F 9894 | 241839 | ℄ | | 296.196 | | 2.45 A | Firm Glacial Clay (Fill) | | |
| P#2 | | | | | | 4.85 B | Firm Silty Glacial Clay | | |
| | | | | | | 11.00 C | Stiff Silty Clay | | |
| | | | | | | 14.65 D | Very Firm Glacial Clay | | |
| | | | | | | | w/ occ. Sand Seams | | |
| | | | | | | 19.65 E | Soft Shale | | |
| | | | | | | 22.25 F | Firm Shale | | |

TO BE CODED BY BRIDGES & STRUCTURES

CONTROL CARD FOR SOILS PLOTTING
BY COMPUTER. RUN PROGRAM # 224012.
TO BE CODED BY BRIDGES & STRUCTURES

NAME:

CHGE. CODE 80-

PHONE:

| FUNCTION | SYSTEM | COUNTY | PROJECT CONTROL NO. CONTROL SECTION | PAREN. NO. | DESIGN NO. | JOB NO. | CARD NUMBER |
|---|---|---|---|---|---|---|---|
| 2 1 1 1 | | | | | | | |

COUNTY Polk

TOWNSHIP

RANGE W E

City of West Des Moines

SECTION

PROJECT

DESIGN NO.

FILE NO. ROUTE NO. I-235

TYPE AND SIZE OF BRIDGE: 42nd St Bridge I-235

BRIDGE OVER: Center Pier

AT STATION

ELEVATION STREAM BED

ELEVATION FTG.

PAGE 1 OF 1

L. Saint Ken

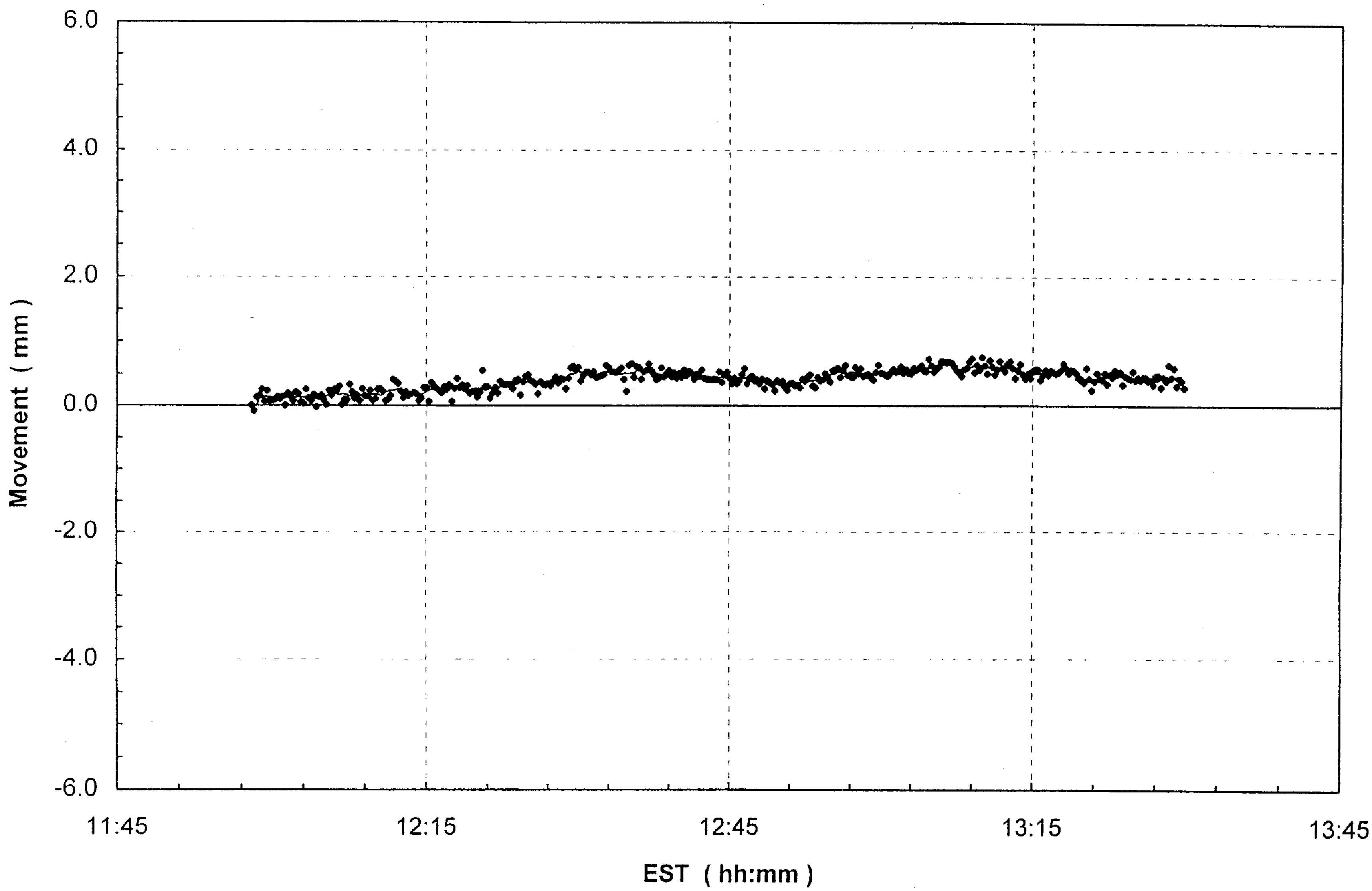
CHIEF OF PARTY

# APPENDIX F

## REFERENCE BEAM MONITORING

# Reference Beam Monitoring

## Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA

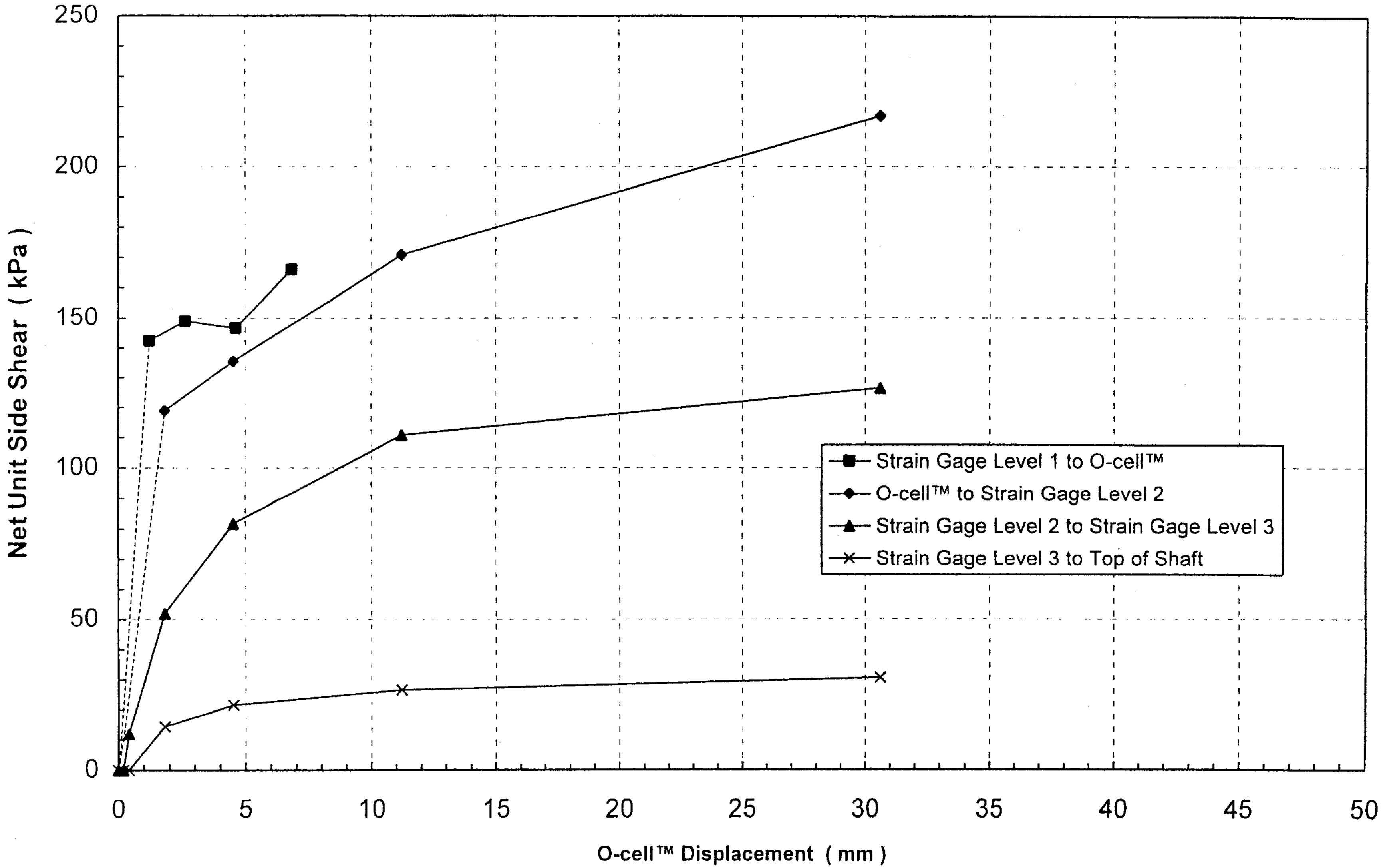


# APPENDIX G

NET UNIT SHEAR CURVES

# Net Unit Side Shear Curves

## Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA

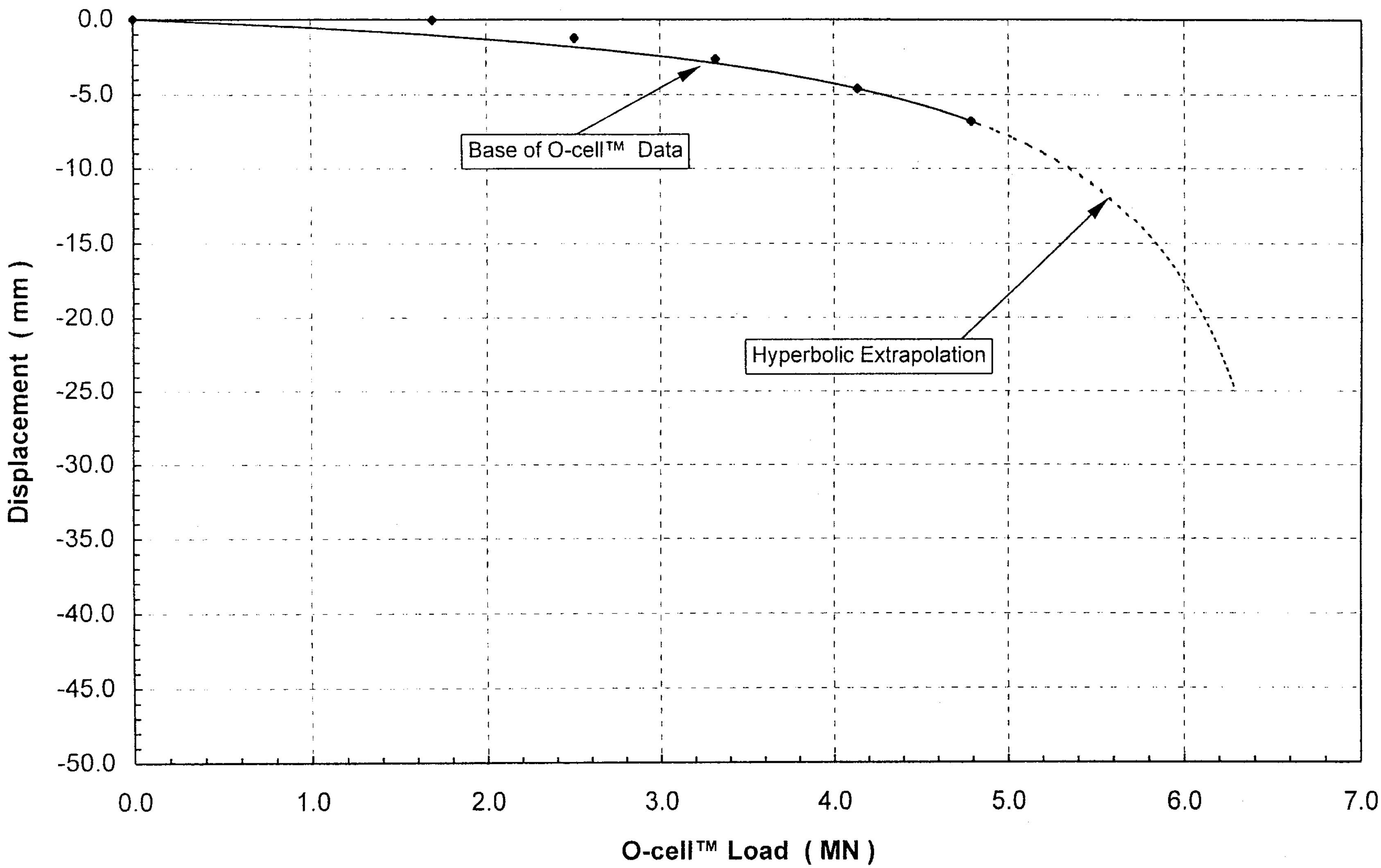


# APPENDIX H

## HYPERBOLIC CURVE FITTING

## Hyperbolic Curve Fit

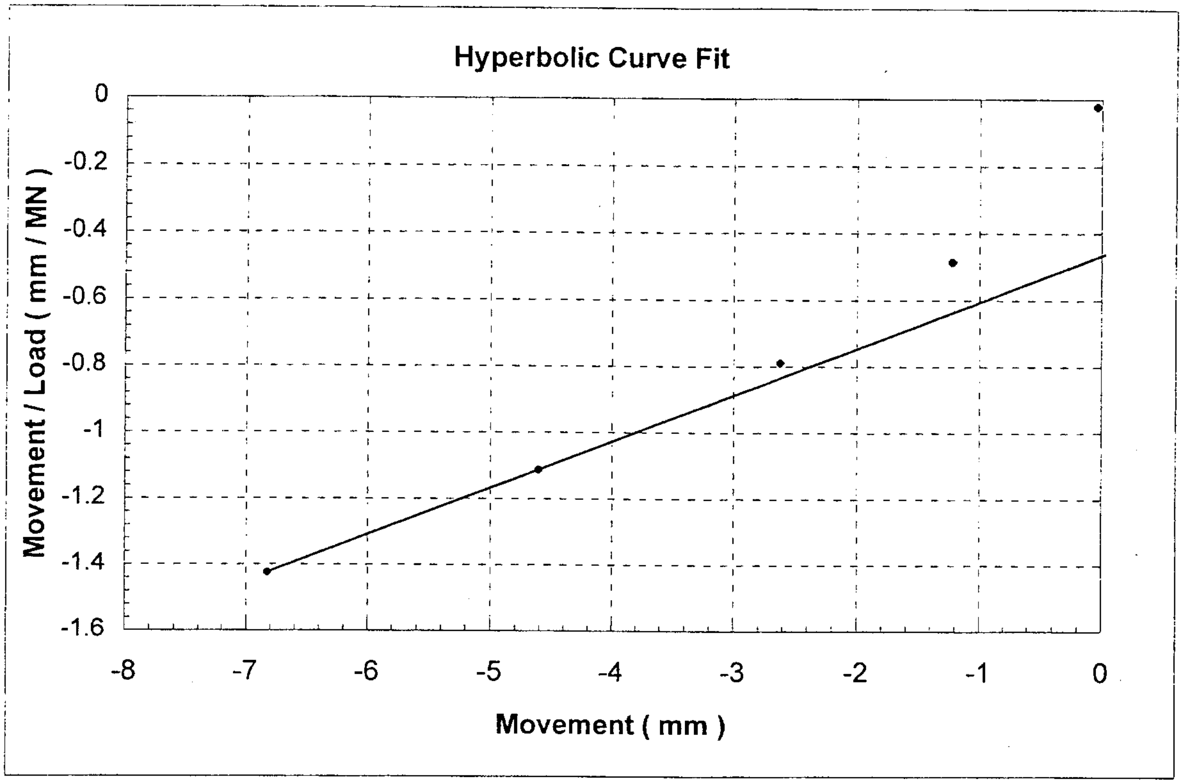
### Test Shaft #1 - 42nd Street / I-235 Overpass - Des Moines, IA



## Table H-1: Hyperbolic Curve Fit of Downward Base of O-cell™ Movement

| Gross Load ( MN ) | Down* ( mm ) | $Y_d$* ( mm/MN ) | $Y_{d\ calc}$ ( mm/MN ) | Gross $Load_{calc}$ ( MN ) |
|---|---|---|---|---|
| 0.00 | 0.00 | - | - | - |
| 0.88 | 0.04 | 0.049 | -0.461 | -0.09 |
| 1.69 | -0.04 | -0.022 | -0.472 | 0.08 |
| 2.51 | -1.22 | -0.486 | -0.638 | 1.91 |
| 3.32 | -2.62 | -0.789 | -0.835 | 3.14 |
| 4.14 | **-4.60** | **-1.113** | -1.113 | 4.14 |
| 4.79 | **-6.82** | **-1.424** | -1.424 | 4.79 |

* Values in **bold** are used in the curve fit.




SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 1 |
| R Square | 1 |
| Adjusted R S | 65535 |
| Standard Erro | 0 |
| Observations | 2 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 0.048377116 | 0.048377116 | 0 | #NUM! |
| Residual | 0 | 3.00753E-30 | 65535 | | |
| Total | 1 | 0.048377116 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -0.46664851 | 0 | 65535 | #NUM! | -0.46664851 | -0.46664851 | -0.466648514 | -0.46664851 |
| X Variable 1 | 0.140382789 | 0 | 65535 | #NUM! | 0.140382789 | 0.140382789 | 0.140382789 | 0.140382789 |

# APPENDIX I

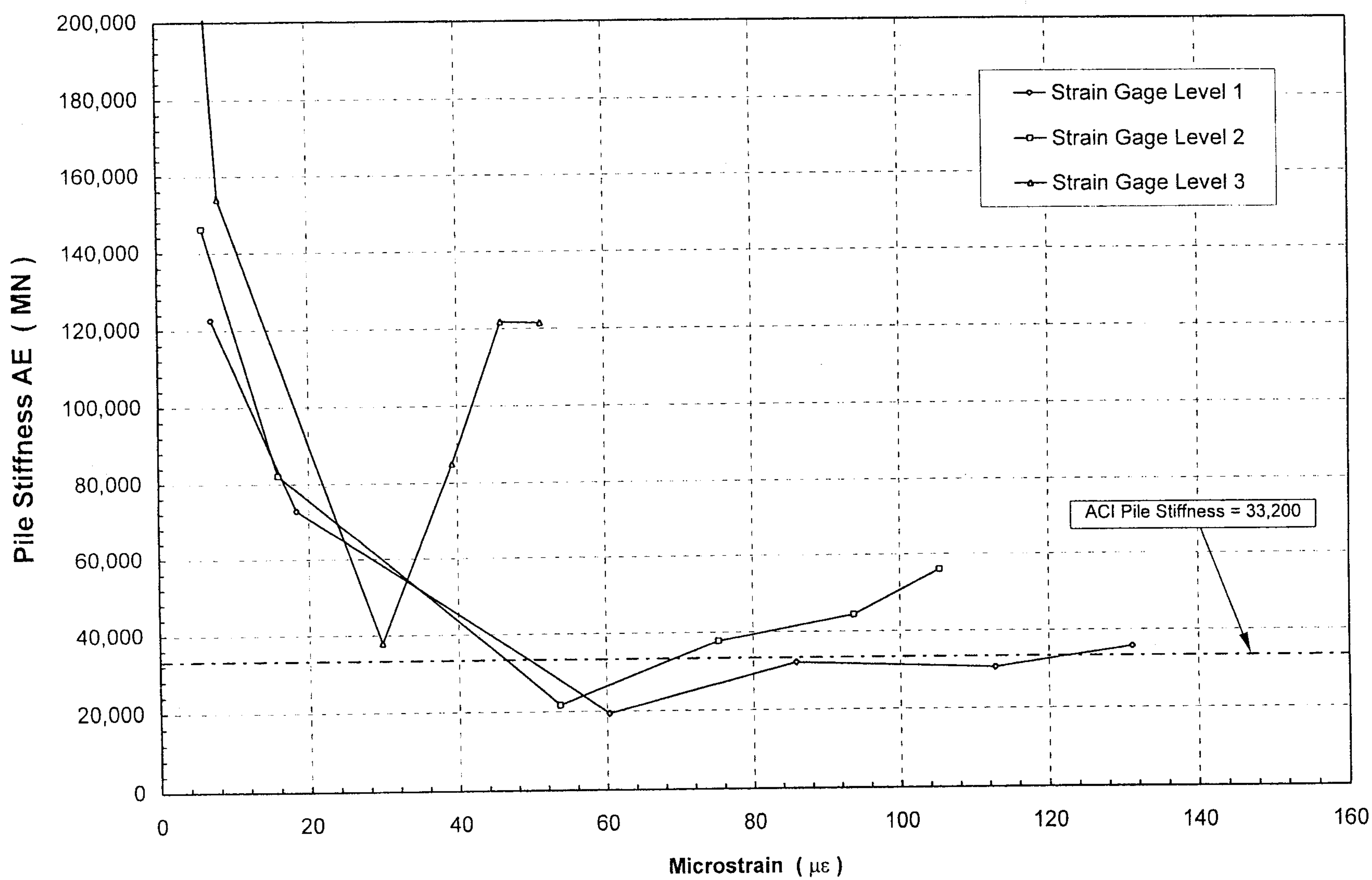
## SHAFT STIFFNESS ESTIMATION

## Table I-1: Tangent Stiffness Analysis for Strain Gage Levels 1, 2 and 3

| O-cell™ | | Strain Gage Level 1 | | | Strain Gage Level 2 | | | Strain Gage Level 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Load (MN) | Δ Load (MN) | μ Strain (με) | Δ μ Strain (με) | AE * (MN) | μ Strain (με) | Δ μ Strain (με) | AE * (MN) | μ Strain (με) | Δ μ Strain (με) | AE * (MN) |
| 0.00 | - | 0.0 | - | - | 0.0 | - | - | 0.0 | - | - |
| 0.88 | 0.88 | 7.1 | 7.1 | 122,572 | 6.0 | 6.0 | 146,193 | 2.8 | 2.8 | 311,648 |
| 1.69 | 0.82 | 18.4 | 11.2 | 72,723 | 15.9 | 9.9 | 82,044 | 8.1 | 5.3 | 153,982 |
| 2.51 | 0.82 | 60.3 | 42.0 | 19,430 | 53.6 | 37.7 | 21,620 | 29.7 | 21.6 | 37,777 |
| 3.32 | 0.82 | 85.9 | 25.6 | 31,891 | 75.3 | 21.7 | 37,629 | 39.3 | 9.6 | 84,891 |
| 4.14 | 0.82 | 112.8 | 26.9 | 30,286 | 93.7 | 18.4 | 44,244 | 46.0 | 6.7 | 121,757 |
| 4.79 | 0.65 | 131.1 | 18.3 | 35,584 | 105.4 | 11.7 | 55,948 | 51.4 | 5.4 | 121,485 |

* Tangent Pile Stiffness Calculation: AE = Δ Load / Δ μ Strain

## Figure I-1: Tangent Pile Stiffness Analysis for Strain Gage Levels 1, 2 and 3



# APPENDIX J

## POST TEST GROUTING PROCEDURE

# POST-TEST GROUTING PROCEDURES FOR PRODUCTION DRILLED SHAFTS TESTED WITH AN OSTERBERG CELL

During the O-cell™ test, the shaft breaks on a horizontal plane separating the upper section above the O-cell™ (upper side-shear) from the lower section below (combined end bearing and lower side shear). This creates an annular space, the size of which depends on the shaft/O-cell™ geometry and the expansion of the O-cell™.

When a production shaft has been tested, the engineer may want to include the end bearing component from the lower section in order to obtain sufficient capacity of the production shaft. In such cases the contractor will be required to grout the O-cell™ and the annular space around the O-cell™ in order to allow load transfer to the lower side shear and end bearing.

## POST-TEST GROUTING OF OSTERBERG CELLS

a) The grout shall consist of Portland cement and water only, NO SAND. The grout shall be fluid and pumpable. An initial mix consisting of 4 to 6 gallons of water per 95-lb bag of cement is recommended. Adjust water to obtain desired consistency.
b) The mixing shall be thorough to ensure that there are no lumps of dry cement. Pass the grout through a window screen mesh before pumping.
c) Connect the grout pump outlet to one hydraulic line of the O-cell™. Open the other line and establish a flow of water through the system.
d) Pump the grout through the O-cell™ hydraulic line while collecting the effluent from the bleed line. Monitor characteristics of effluent material and when it becomes equivalent to the grout being pumped, stop pumping.
e) Take three samples of the grout for compression testing @ 28 days, if required.

| Recommended pre-mixed amount of grout for grouting of O-cell™: | | | | |
|---|---|---|---|---|
| O-cell Diameter (Inches) | 13 | 21 | 26 | 34 |
| Grout Volume (Cubic Feet) | 4 | 7 | 9 | 13 |

## POST-TEST GROUTING OF ANNULAR SPACE AROUND OSTERBERG CELLS

a) Prepare a fluid grout mix consisting of Portland cement and water only, NO SAND. The mixing procedures should be as outlined for grouting the O-cells™. The quantity of grout should be at least three (3) times the theoretical volume required to fill the annular space and grout pipes.
b) Pump water and establish a flow through each of the grout pipes (two per shaft).
c) Pump the fluid grout through one of the grout pipes until the grout is observed flowing from the second grout pipe or until 1.5 times the theoretical volume has been pumped.
d) If no return of grout is observed from the second grout pipe, transfer the pump to the second pipe and pump grout through it until 1.5 times the theoretical volume has been pumped.
e) If higher strength grout is deemed necessary, immediately proceed with pumping the higher strength grout (which may be a sand mix). The pumping procedures for this grout will be the same as described above for the initial cement-water grout. **The entire grouting operation must be completed before the set time for the initial grout has elapsed.**
f) Take three (3) samples of each type of grout for compression testing @ 28 days.

| Recommended pre-mix amount of grout for grouting of annular space: | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Shaft Diameter (Feet) | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Grout Volume (Cubic Feet) | 25 | 30 | 40 | 50 | 65 | 80 | 100 | 125 |