# REPORT ON DRILLED SHAFT LOAD TESTING (OSTERBERG METHOD)

## West Test Shaft - US 36 over Republican River Republic Co., KS (LT-8718-1)

**Prepared for:** Kansas Department of Transportation
915 SW Harrison, 9th Floor
Topeka, Kansas 66612

**Attention:** Mr. Steve Burnett

**PROJECT NUMBER: LT-8718-1, April 13, 2001**


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LOADTEST INC.

DEEP FOUNDATION TESTING, EQUIPMENT & SERVICES • SPECIALIZING IN OSTERBERG CELL TECHNOLOGY

April 13, 2001

**Kansas Department of Transportation**
**915 SW Harrison, 9th Floor**
**Topeka, Kansas 66612**

**Attention: Mr. Steve Burnett**

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**Data Report: West Test Shaft - US 36 over Republican River**
**Location: Republic Co., KS**

Dear Sirs,

This report provides data and evaluation for the Osterberg Cell load test performed for Kansas Department of Transportation on West Test Shaft - US 36 over Republican River (LTI project LT-8718-1). Mr. M. D. Ahrens and Mr. W. G. Ryan of LOADTEST, Inc. carried out the test on April 5, 2001. Representatives of the Kansas Department of Transportation and Midwest Foundations Co. observed the test. Throughout this report, we use SI units as primary and English units as secondary.

Midwest Foundations Co. constructed the dedicated test shaft socketed in rock on March 28, 2001. Assembly and installation of the O-cell™ and instrumentation was carried out under the direction of Mr. W. G. Ryan of LOADTEST, Inc. The 1829 mm (72 in) test shaft was constructed dry to a total depth of 14.83 m (48.7 ft). The shaft was started with a temporary 1829-mm (72-in) I.D. surface casing. An auger and clean-out bucket were used for drilling and cleaning the shaft. After the carrying frame and O-cell™ assembly was inserted in the shaft, concrete was placed by pump through a 127-mm (5-in) O.D. pipe into the base of the shaft until the top of the concrete reached an elevation of +430.06 m (+1410.9 ft). The O-cell™ was located 0.76 m (2.5 ft) above the tip of shaft. No unusual problems occurred during construction of the shaft. The Kansas Department of Transportation observed construction of the shaft. Table B contains a summary of dimensions, elevations and shaft properties used in the data evaluations.

The sub-surface stratigraphy at the test shaft location is reported to consist of alluvial silty sand to elevation +431.24 m (+1414.81 ft) underlain by the Graneros Shale Formation to an undetermined depth. Appendix E contains soil boring logs of conditions near the test shaft. More detailed geologic information can be obtained from the Kansas Department of Transportation.

The key elements of the acquired data are as follows:

- Average Net Unit Side Shear Values, Table A.
- Summary of Dimensions, Elevations & Shaft Properties, Table B.

- Schematic Section of Test Shaft, Figure A.
- Osterberg Cell Load-Movement Curves, Figure 1.
- Equivalent Top Load Curve, Figure 2.
- Strain Gage Load Distribution Curves, Figure 3.
- Combined End Bearing and Lower Side Shear Creep Limit, Figure 4.
- Upper Side Shear Creep Limit, Figure 5.

- Field Data & Data Reduction, Appendix A (5 pages).
- O-cell™ and Instrumentation Calibration Sheets, Appendix B.
- Construction of the Equivalent Top-Loaded Load-Settlement Curve, Appendix C.
- O-cell™ Method for Determining Creep Limit Loading, Appendix D.
- Soil Boring Logs, Appendix E.
- Reference Beam Monitoring, Appendix F.
- Net Unit Shear and Unit End Bearing Curves, Appendix G.

Standard O-cell™ instrumentation included three LVWDTs (Linear Vibrating Wire Displacement Transducers - Geokon Model 4450 series) positioned between the lower and upper plates of the O-cell™ assembly to measure expansion (Table 2). Compression of the pile above the top O-cell™ assembly was measured by two telltales extending to the ground surface. Telltale movements were measured by digital dial gages (CDI DCW series) at the ground surface (Table 1). Two digital dial gages attached to a reference beam monitored the top of the reinforcing frame (top of shaft) movement (Table 1).

The reference beam consisted of a 6-m (20-ft) steel wide flange section supported on wood dunnage. The supports were located approximately one and a half shaft diameters from the center of the test shaft. The beam was not shaded during the test, however, the sky was completely overcast. A Leica NA 3003 digital survey level monitored the reference beam for movement during testing from a distance of approximately 11 m (36 ft) (Appendix F). A maximum upward movement of 0.34 mm (0.013 in) was observed for the reference beam and the top of shaft movements have been corrected accordingly (Table 1).

Two levels of four sister bar vibrating wire strain gages (Geokon Model 4900 series) were installed in the shaft above the O-cell™. Details concerning the strain gage placement appear in Table B and Figure A. The strain gages were used to assess the side shear load transfer of the shaft above the Osterberg cell. The strain gages were positioned as recommended by LOADTEST, Inc. and approved by the Kansas Department of Transportation.

The construction of the shaft included placing two lines of PVC pipe, starting at the top-of-shaft and terminating at the top of the bottom plate to vent the break in the shaft at the base of the O-cell™. In addition, they permited the application of water in the fracture plane to maintain equilibrium with the existing water table.

American Equipment and Fabricating Corporation carried out a pressure vs. load calibration of the O-cell™ to 13.74 MN (3095 kips) prior to delivery to the test site (See Appendix B). Both a Bourdon pressure gage (0-10,000 psi) and a voltage pressure transducer were used to measure the pressure applied to the O-cell™ at each load interval. We used the Bourdon pressure gage for operating the pump 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.

**Note:** 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 load curve. In addition, the buoyant weight of the shaft above the O-cell™ is subtracted a second time, since in a top load test, the applied load is equal to the soil resistance less the buoyant weight of the shaft. For this test we calculated a buoyant weight of shaft of 0.27 MN (60 kips) above the O-cell™.

As with all of our tests, we begin by pressurizing the O-cells™ in order to break the tack welds that hold the cell closed (for handling and construction of the shaft) and to form the fracture plane in the concrete surrounding the base of the O-cells™. After the break occurs, we immediately release the pressure and then begin the test. 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 6.21 MPa (900 psi) to the O-cell™.

The Osterberg cell load test was conducted as follows: We pressurized the 870-mm (34-in) diameter O-cell™, with its base located 0.76 m (2.5 ft) 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 19.86 MPa (2880 psi) resulting in a bi-directional gross O-cell™ load of 7.90 MN (1776 kips). The loading was halted after load interval 1L-6 because the O-cell™ was expanding rapidly and a higher load could not be achieved. The O-cell™ was then depressurized in four decrements and the test was concluded.

We applied the load increments in general accordance with the Quick Load Test Method (ASTM D1143), holding each successive load increment constant for eight minutes by manually adjusting the O-cell™ pressure. We used approximately one minute to move between increments. The data logger automatically recorded the instrument readings every 30 seconds, but herein we report only the 1, 2, 4 and 8 minute readings during each increment of maintained load.

## DISCUSSION OF RESULTS

**Combined End Bearing and Lower Side Shear:** The maximum downward applied load was 7.90 MN (1776 kips) which occurred at load interval 1L-6 (Table 3, Figure 1). At this loading, the downward movement of the O-cell™ base was 28.49 mm (1.122 in). The side shear capacity of the 0.76 m (2.5 ft) shaft section below the O-cell™ is calculated to be 0.75 MN (168 kips) assuming an average socket unit side shear value of 171 kPa (3.58 ksf) (Appendix G) and a nominal shaft diameter of 1829 mm (72 in). The maximum applied load to end bearing is then 7.15 MN (1608 kips) and the unit end bearing at the base of the shaft is calculated to be 2723 kPa (56.9 ksf) at the above noted displacement. A unit end bearing curve is presented in Appendix G.

**Upper Side Shear:** The maximum upward applied *net load* was 7.63 MN (1716 kips) which occurred at load interval 1L-6 (Table 3, Figure 1). At this loading, the upward movement of the O-cell™ top was 43.60 mm (1.717 in). The following section provides additional unit side shear estimates based on strain gage data.

**Strain Gage Results:** The strain gage data appear in Table 5. On the day of the test, the concrete unconfined compressive strength was reported to be 37.4 MPa (5419 psi). We used the ACI formula ($E_c=57000\sqrt{f'_c}$) to calculate an elastic modulus for the concrete. This, combined with the area of reinforcing steel and nominal shaft diameter, provided an average unit pile stiffness (AE) of 76,500 MN (17,200,000 kips) above the O-cell™. Net unit side shear curves based on the strain gage data and estimated shaft stiffness are presented in Appendix G. Estimated unit side shear values for the shaft based on the strain gage data and estimated shaft stiffness for 1L-6 follow in Table A:

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

| Load Transfer Zone | Net Unit Side Shear * |
|---|---|
| Average Socket – Top of Concrete to O-cell™ | 183 kPa (3.83 ksf) |
| Top of Concrete to Strain Gage Level 2 | 108 kPa (2.26 ksf) |
| Strain Gage Level 2 to Strain Gage Level 1 | 117 kPa (2.44 ksf) |
| Strain Gage Level 1 to O-cell™ | 291 kPa (6.07 ksf) |

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

**Creep Limit**: See Appendix D for our O-cell™ method for determining creep limit loading. The combined end bearing and lower side shear creep data (Table 4) indicate that a creep limit of 1.4 MN (315 kips) was reached at a movement of 1.9 mm (0.08 in) (Figure 4). The upper side shear creep data (Table 4) indicate that a creep limit of 5.2 MN (1169 kips) was reached at a movement of 4.5 mm (0.18 in)

(Figure 5). A shaft top loaded 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 6.6 MN (1491 kips).

**Equivalent Top Load**: Figure 2 presents the equivalent top-loaded load-settlement curves for the shaft as constructed. 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. 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 successfully loaded to a combined side shear and end-bearing load of 15.5 MN (3492 kips). For a top loading of 7.7 MN (1721 kips), the adjusted test data indicate this shaft would settle approximately 6.4 mm (0.25 in) of which 0.5 mm (0.02 in) is estimated elastic compression. For a top loading of 10.3 MN (2325 kips) the adjusted test data indicate this shaft would settle approximately 12.7 mm (0.50 in) of which 0.8 mm (0.03 in) is estimated elastic compression.

Note that, as explained previously, the equivalent top load curve applies to incremental loading durations of eight 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 Telltales**: The measured maximum shaft compression, averaged from two telltales, is 0.18 mm (0.007 in) at 1L-6 (Table 1). Using a shaft stiffness of 76,500 MN (17,200,000 kips) and the load distribution in Figure 3 at 1L-6, we calculated an elastic compression of 0.25 mm (0.010 in) over the length of the compression telltales. We believe this fair agreement provides evidence that our values of the estimated shaft stiffness are reasonable and that the O-cells™ loaded the shaft in accord with its calibrations.

**Differential O-cell™ Opening:** The three LVWDTs measuring O-cell™ expansion allow us to evaluate the differential opening of the O-cell™ (Table 2). We calculate a maximum differential expansion of 1.22 mm (0.048 in) (0.07°) across the nominal 1829 mm (72 in) diameter of the bottom of the shaft at the 1L-6 maximum loading. This suggests uniform concrete above and below the O-cell™.

The data evaluations provided in this report is based on information (i.e. shaft diameter, elevations and concrete strength) provided by others. The engineer, therefore, should come to his/her own conclusions with regard to the analytical information.

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.

Prepared for LOADTEST, Inc. by

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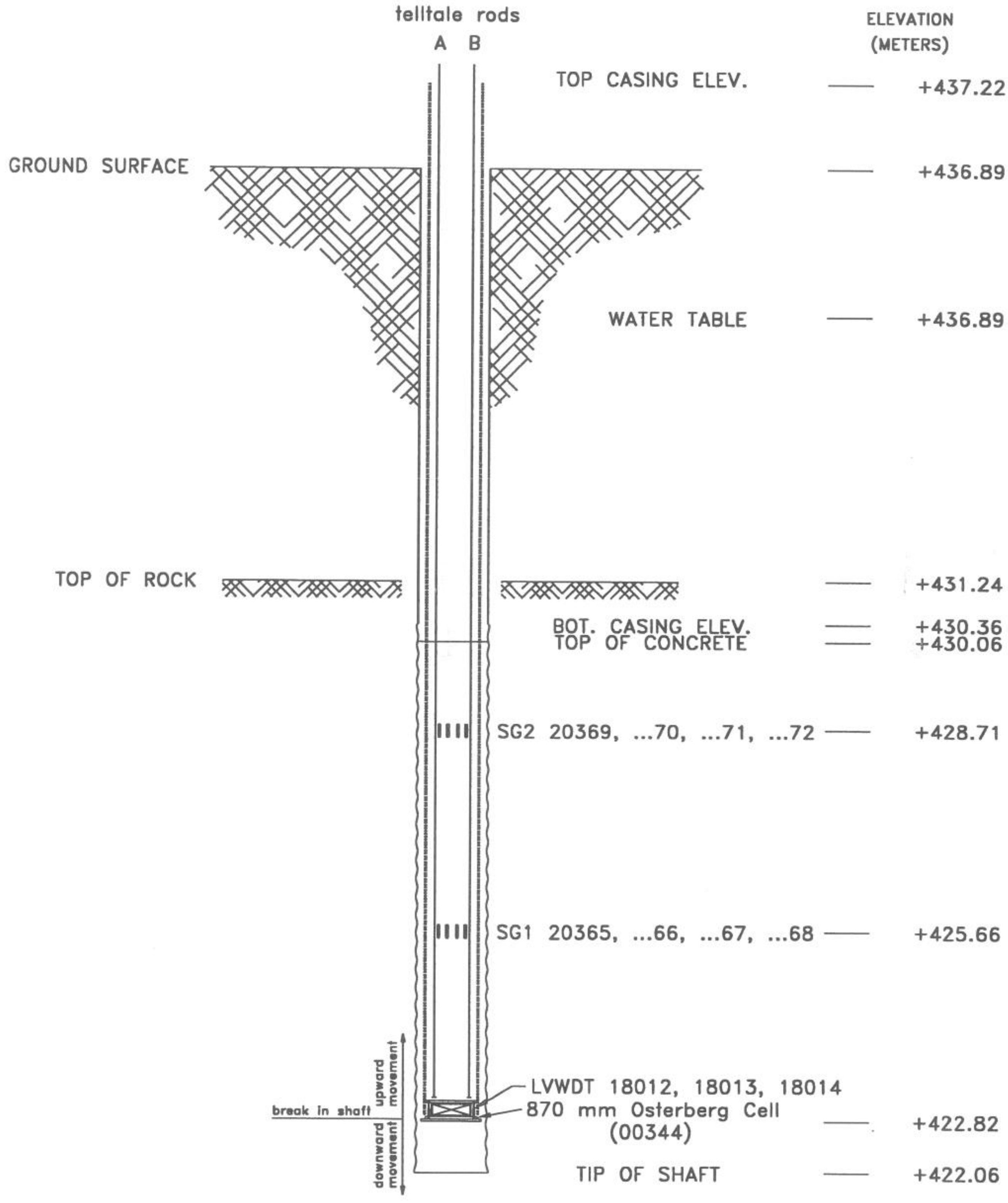
## TABLE B:
## SUMMARY OF DIMENSIONS, ELEVATIONS & SHAFT PROPERTIES

| | | | | |
|---|---|---|---|---|
| **Shaft:** | | | | |
| Nominal shaft diameter (EL +430.06 m to +422.82 m) | = | 1829 mm | | 72 in |
| O-cell™: 0034-4 | = | 870 mm | | 34 in |
| Bouyant weight of pile above base of O-cell™ | = | 0.27 MN | | 60 kips |
| Estimated shaft stiffness, AE (EL +430.06 m to +422.82 m) | = | 76,500 MN | | 17,200,000 kips |
| | | | | |
| Elevation of Ground Surface | = | +436.89 m | | +1433.4 ft |
| Elevation of water table | = | +434.68 m | | +1426.1 ft |
| Elevation of top of shaft concrete | = | +430.06 m | | +1410.9 ft |
| Elevation of base of O-cell™ (The break between upward and downward movement.) | = | +422.82 m | | +1387.2 ft |
| Elevation of shaft tip | = | +422.06 m | | +1384.7 ft |
| | | | | |
| **Casings:** | | | | |
| Elevation of top of temporary casing (1829 mm O.D.) | = | +437.22 m | | +1434.4 ft |
| Elevation of bottom of temporary casing (1829 mm O.D.) | = | +430.36 m | | +1411.9 ft |
| | | | | |
| **Compression Sections:** | | | | |
| Elevation of top of telltale used for upper shaft compression | = | +430.06 m | | +1410.9 ft |
| Elevation of bottom of telltale used for upper shaft compression | = | +423.17 m | | +1388.3 ft |
| | | | | |
| **Strain Gages:** | | | | |
| Elevation of strain gage Level 2 | = | +428.71 m | | +1406.5 ft |
| Elevation of strain gage Level 1 | = | +425.66 m | | +1396.5 ft |
| | | | | |
| **Miscellaneous:** | | | | |
| Top plate diameter (38 mm thickness) | = | 1676 mm | | 66 in |
| Bottom plate diameter (51 mm in thickness) | = | 1676 mm | | 66 in |
| Carrying frame size (2 No.) | = | | C4 x 7.25 | |
| Spiral size (1524 mm spacing) | = | M 16 | | # 5 |
| Rebar cage diameter | = | 1676 mm | | 66 in |
| Unconfined compressive concrete strength | = | 37.4 MPa | | 5419 psi |
| O-cell™ LVWDTs @ 0°, 180° and 90° with radius | = | 500 mm | | 20 in |

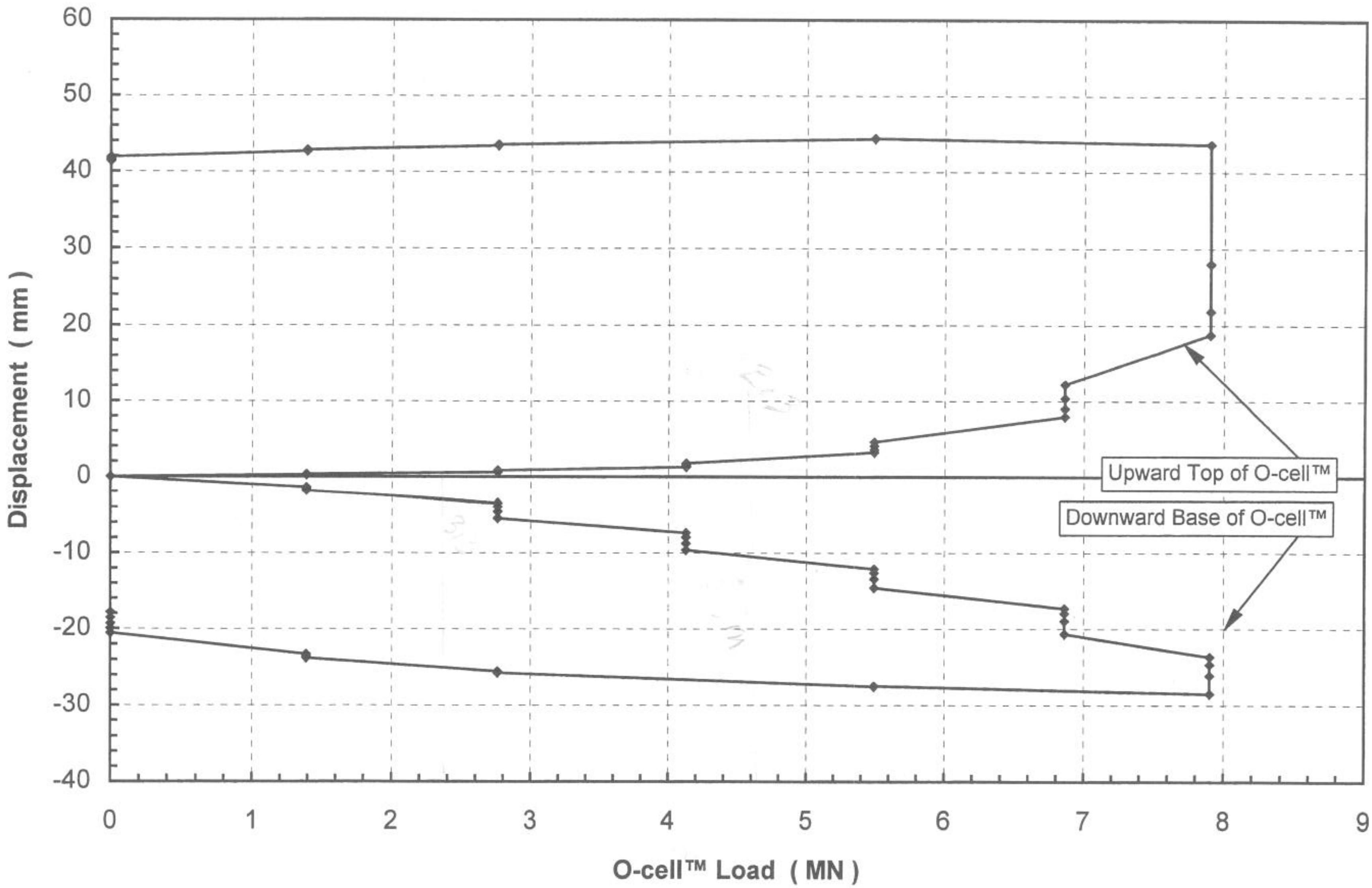
NOTE:
- NOMINAL SHAFT DIAMETER 1829 mm




| | | | |
|---|---|---|---|
| LOADTEST | 2631-D NW 41st St.<br>Gainesville, FL 32606<br>Phone 800-368-1138<br>FAX (352) 378-3934 | SCHEMATIC SECTION OF<br>WEST TEST SHAFT | LT-8718-1 US36<br>Over Republican River<br>Scandia, Kansas<br>FIGURE A |

# Osterberg Cell Load-Movement Curves

## West Test Shaft - US 36 over Republican River - Republic Co., KS



# Equivalent Top Load-Movement Curves

## West Test Shaft - US 36 over Republican River - Republic Co., KS

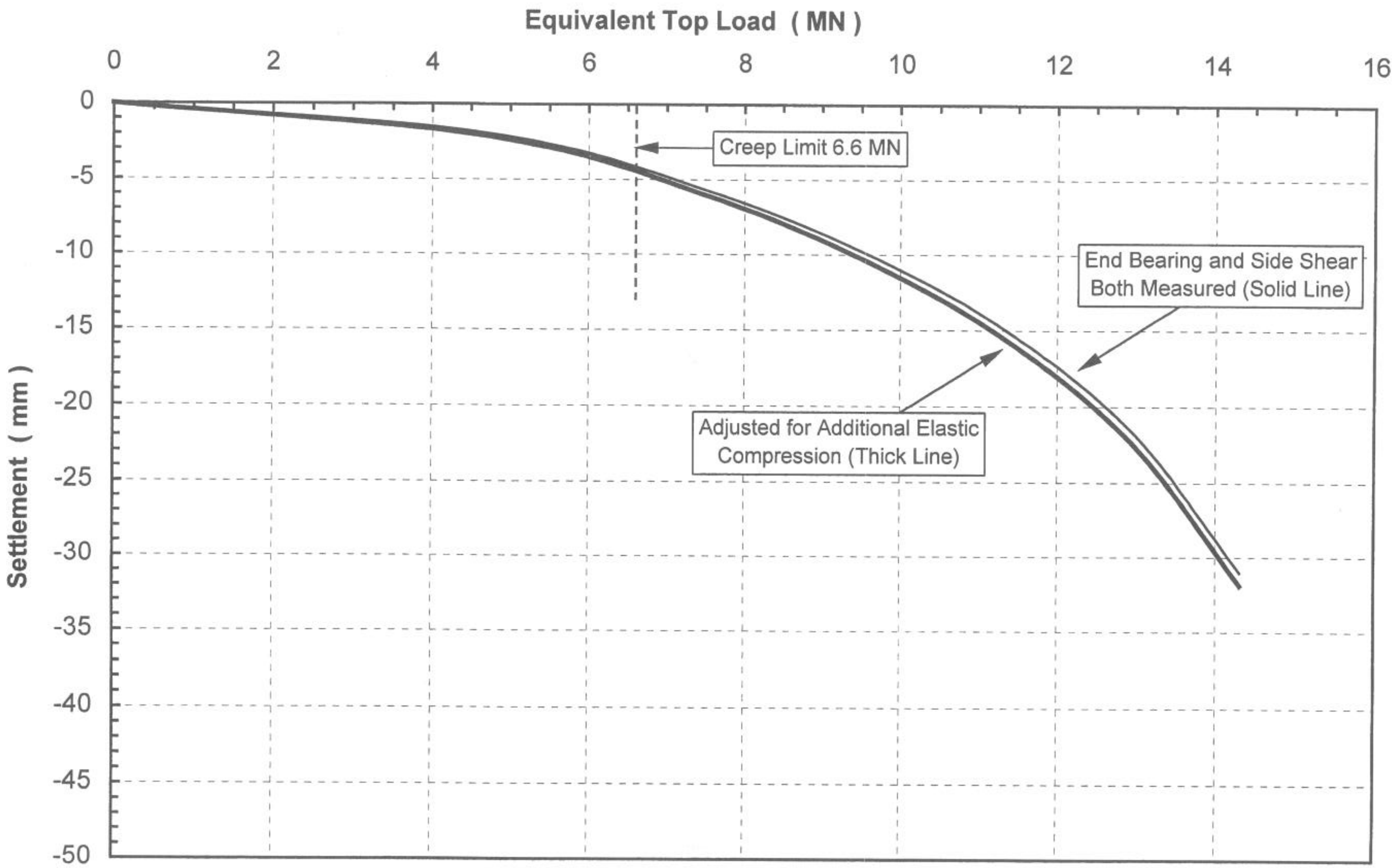



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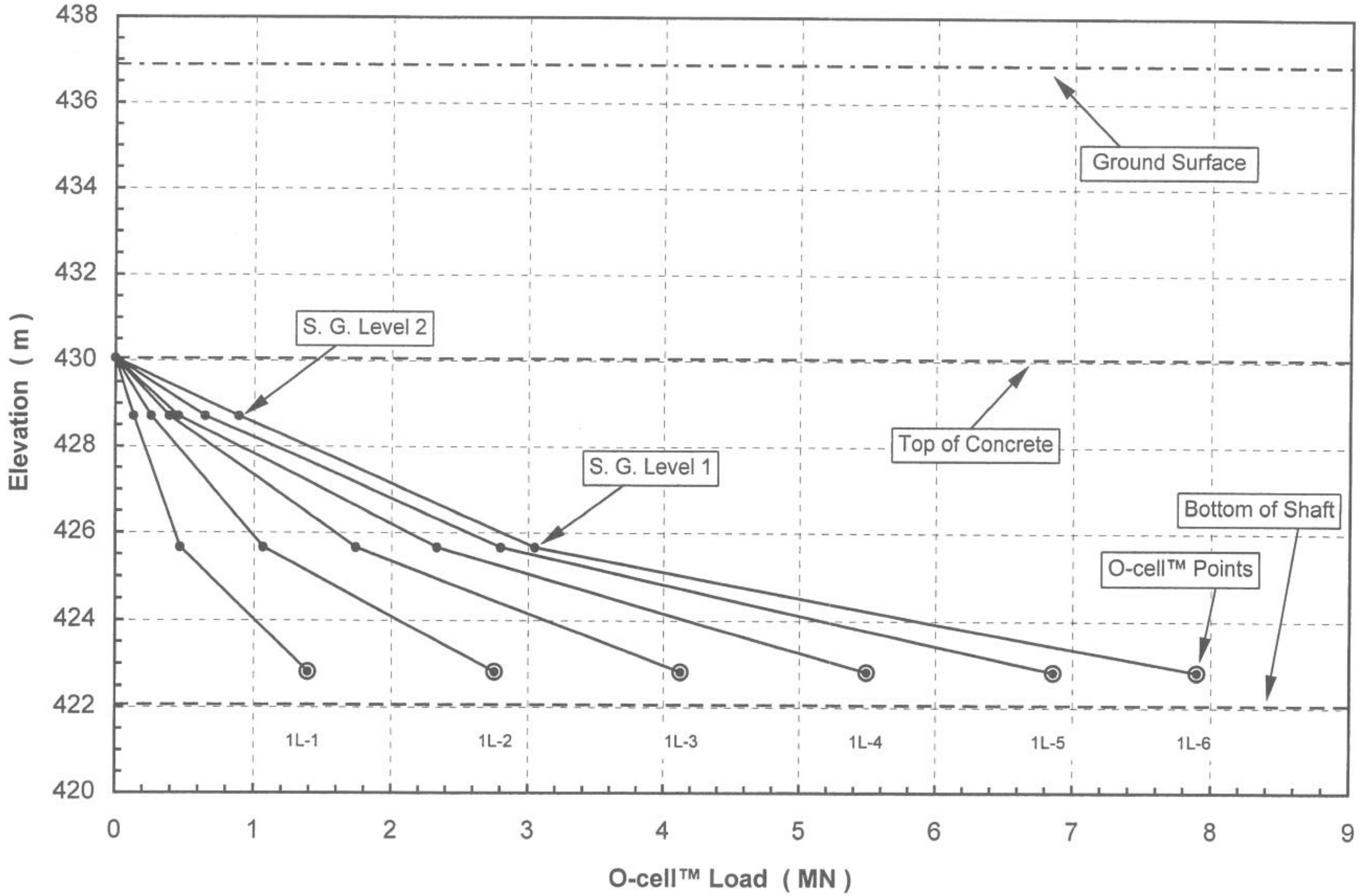
Figure 2 of 5

## Strain Gage Load Distribution Curves

### West Test Shaft - US 36 over Republican River - Republic Co., KS



## Combined End Bearing and Lower Side Shear Creep Limit

### West Test Shaft - US 36 over Republican River - Republic Co., KS

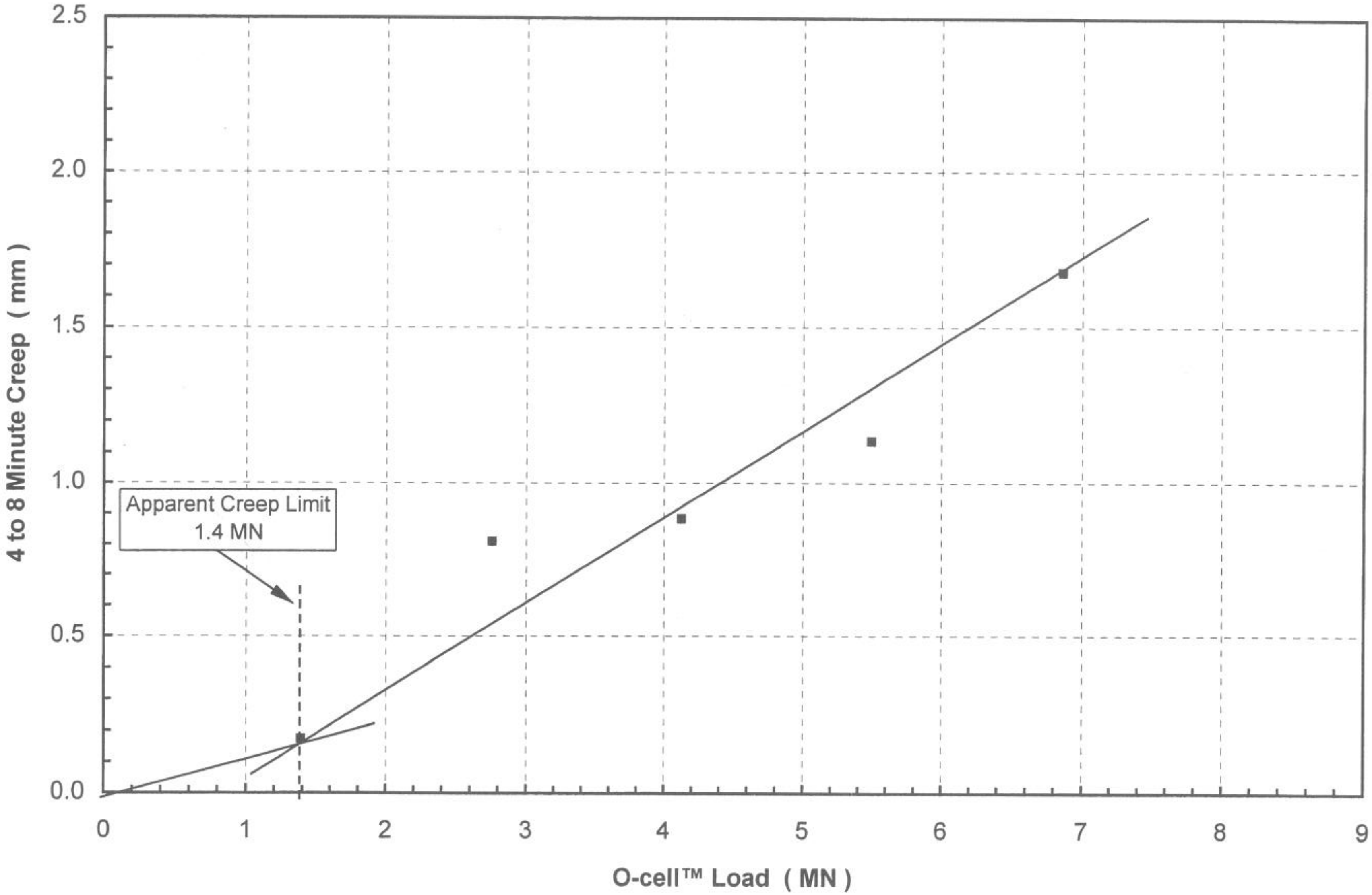



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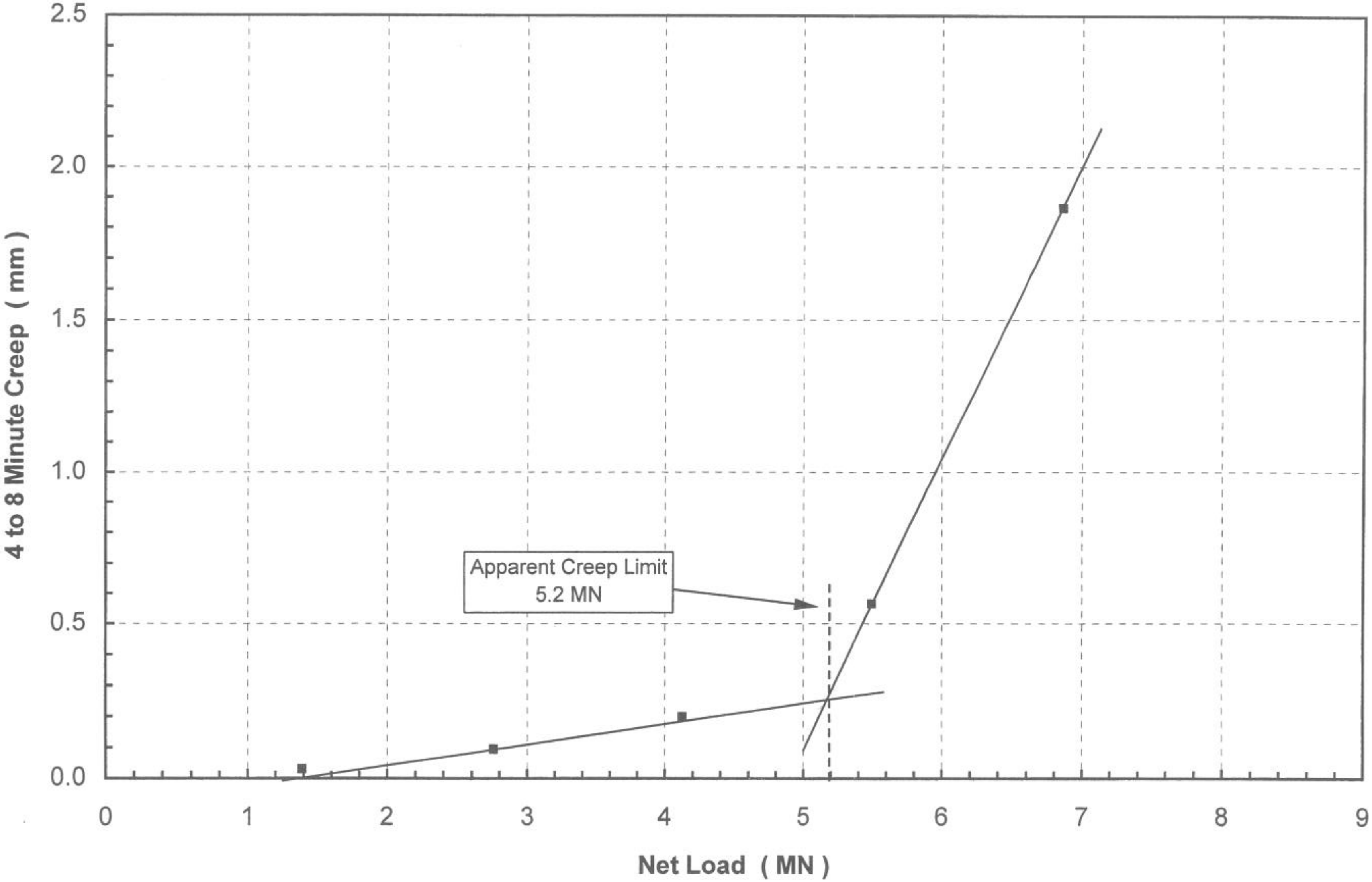
Figure 4 of 5

# Upper Side Shear Creep Limit

## West Test Shaft - US 36 over Republican River - Republic Co., KS



# APPENDIX A

## FIELD DATA & DATA REDUCTION

## Upward Top of Shaft Movement and Shaft Compression
## West Test Shaft - US 36 over Republican River - Republic Co., KS

| Load Test Increment | Hold Time (minutes) | Time (h:m:s) | O-cell™ Pressure (MPa) | O-cell™ Load (MN) | Ref. Beam * (mm) | Top of Shaft TOS A (mm) | Top of Shaft TOS B (mm) | Top of Shaft Average (mm) | Telltales Comp A (mm) | Telltales Comp B (mm) | Telltales Average (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 L - 0 | - | 18:51:00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 L - 1 | 1 | 19:03:30 | 3.45 | 1.39 | 0.01 | 0.21 | 0.22 | 0.23 | 0.01 | 0.02 | 0.01 |
| 1 L - 1 | 2 | 19:04:30 | 3.45 | 1.39 | 0.01 | 0.22 | 0.23 | 0.23 | 0.01 | 0.02 | 0.01 |
| 1 L - 1 | 4 | 19:06:30 | 3.45 | 1.39 | 0.01 | 0.24 | 0.25 | 0.26 | 0.01 | 0.02 | 0.01 |
| 1 L - 1 | 8 | 19:10:30 | 3.45 | 1.39 | 0.02 | 0.26 | 0.26 | 0.29 | 0.01 | 0.02 | 0.01 |
| 1 L - 2 | 1 | 19:12:00 | 6.89 | 2.76 | 0.03 | 0.49 | 0.52 | 0.54 | 0.03 | 0.03 | 0.03 |
| 1 L - 2 | 2 | 19:13:00 | 6.89 | 2.76 | 0.04 | 0.55 | 0.57 | 0.60 | 0.04 | 0.03 | 0.04 |
| 1 L - 2 | 4 | 19:15:00 | 6.89 | 2.76 | 0.04 | 0.60 | 0.63 | 0.65 | 0.04 | 0.04 | 0.04 |
| 1 L - 2 | 8 | 19:19:00 | 6.89 | 2.76 | 0.06 | 0.67 | 0.70 | 0.75 | 0.04 | 0.04 | 0.04 |
| 1 L - 3 | 1 | 19:21:30 | 10.34 | 4.13 | 0.09 | 1.07 | 1.10 | 1.17 | 0.07 | 0.06 | 0.07 |
| 1 L - 3 | 2 | 19:22:30 | 10.34 | 4.13 | 0.09 | 1.19 | 1.22 | 1.30 | 0.08 | 0.06 | 0.07 |
| 1 L - 3 | 4 | 19:24:30 | 10.34 | 4.13 | 0.10 | 1.35 | 1.38 | 1.47 | 0.08 | 0.07 | 0.07 |
| 1 L - 3 | 8 | 19:28:30 | 10.34 | 4.13 | 0.12 | 1.52 | 1.55 | 1.66 | 0.09 | 0.07 | 0.08 |
| 1 L - 4 | 1 | 19:30:30 | 13.79 | 5.49 | 0.16 | 2.91 | 2.93 | 3.08 | 0.13 | 0.09 | 0.11 |
| 1 L - 4 | 2 | 19:31:30 | 13.79 | 5.49 | 0.16 | 3.24 | 3.26 | 3.41 | 0.13 | 0.09 | 0.11 |
| 1 L - 4 | 4 | 19:33:30 | 13.79 | 5.49 | 0.17 | 3.73 | 3.74 | 3.90 | 0.13 | 0.09 | 0.11 |
| 1 L - 4 | 8 | 19:37:30 | 13.79 | 5.49 | 0.18 | 4.27 | 4.28 | 4.46 | 0.14 | 0.10 | 0.12 |
| 1 L - 5 | 1 | 19:39:30 | 17.24 | 6.86 | 0.21 | 7.62 | 7.62 | 7.83 | 0.17 | 0.11 | 0.14 |
| 1 L - 5 | 2 | 19:40:30 | 17.24 | 6.86 | 0.21 | 8.64 | 8.64 | 8.85 | 0.17 | 0.11 | 0.14 |
| 1 L - 5 | 4 | 19:42:30 | 17.24 | 6.86 | 0.23 | 9.97 | 9.96 | 10.19 | 0.17 | 0.12 | 0.14 |
| 1 L - 5 | 8 | 19:46:30 | 17.24 | 6.86 | 0.25 | 11.81 | 11.79 | 12.06 | 0.17 | 0.12 | 0.14 |
| 1 L - 6 | 1 | 19:49:00 | 19.86 | 7.90 | 0.29 | 18.31 | 18.29 | 18.59 | 0.19 | 0.14 | 0.17 |
| 1 L - 6 | 2 | 19:50:00 | 19.86 | 7.90 | 0.30 | 21.40 | 21.37 | 21.68 | 0.19 | 0.14 | 0.17 |
| 1 L - 6 | 4 | 19:52:00 | 19.86 | 7.90 | 0.32 | 27.53 | 27.52 | 27.85 | 0.19 | 0.15 | 0.17 |
| 1 L - 6 | 8 | 19:56:00 | 19.86 | 7.90 | 0.34 | 43.09 | 43.08 | 43.42 | 0.19 | 0.17 | 0.18 |
| 1 U - 1 | 1 | 19:58:00 | 13.79 | 5.49 | 0.29 | 43.98 | 43.92 | 44.24 | 0.14 | 0.16 | 0.15 |
| 1 U - 1 | 2 | 19:59:00 | 13.79 | 5.49 | 0.28 | 43.97 | 43.91 | 44.23 | 0.14 | 0.16 | 0.15 |
| 1 U - 1 | 4 | 20:01:00 | 13.79 | 5.49 | 0.26 | 43.95 | 43.90 | 44.18 | 0.14 | 0.16 | 0.15 |
| 1 U - 2 | 1 | 20:02:30 | 6.89 | 2.76 | 0.21 | 43.27 | 43.20 | 43.44 | 0.05 | 0.10 | 0.08 |
| 1 U - 2 | 2 | 20:03:30 | 6.89 | 2.76 | 0.19 | 43.23 | 43.15 | 43.38 | 0.05 | 0.10 | 0.07 |
| 1 U - 2 | 4 | 20:05:30 | 6.89 | 2.76 | 0.17 | 43.18 | 43.11 | 43.32 | 0.05 | 0.10 | 0.07 |
| 1 U - 3 | 1 | 20:07:00 | 3.45 | 1.39 | 0.14 | 42.69 | 42.61 | 42.79 | 0.00 | 0.07 | 0.03 |
| 1 U - 3 | 2 | 20:08:00 | 3.45 | 1.39 | 0.14 | 42.63 | 42.54 | 42.72 | 0.00 | 0.07 | 0.03 |
| 1 U - 3 | 4 | 20:10:00 | 3.45 | 1.39 | 0.11 | 42.56 | 42.46 | 42.62 | -0.01 | 0.07 | 0.03 |
| 1 U - 4 | 1 | 20:12:00 | 0.00 | 0.00 | 0.07 | 41.87 | 41.79 | 41.89 | -0.06 | 0.03 | -0.02 |
| 1 U - 4 | 2 | 20:13:00 | 0.00 | 0.00 | 0.05 | 41.75 | 41.67 | 41.76 | -0.06 | 0.02 | -0.02 |
| 1 U - 4 | 4 | 20:15:00 | 0.00 | 0.00 | 0.04 | 41.62 | 41.54 | 41.62 | -0.07 | 0.02 | -0.02 |
| 1 U - 4 | 8 | 20:19:00 | 0.00 | 0.00 | 0.02 | 41.52 | 41.43 | 41.50 | -0.07 | 0.02 | -0.02 |
| 1 U - 4 | 16 | 20:27:00 | 0.00 | 0.00 | 0.00 | 41.41 | 41.33 | 41.36 | -0.09 | 0.02 | -0.03 |

* Positive values indicate upward reference beam movement.

## O-cell™ Expansion
## West Test Shaft - US 36 over Republican River - Republic Co., KS

| Load Test Increment | Hold Time (minutes) | Time (h:m:s) | O-cell™ Pressure (MPa) | O-cell™ Load (MN) | O-cell™ Expansion LVWDT 18012 (mm) | O-cell™ Expansion LVWDT 18013 (mm) | O-cell™ Expansion LVWDT 18014 * (mm) | O-cell™ Expansion Average (mm) |
|---|---|---|---|---|---|---|---|---|
| 1L-0 | - | 18:51:00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1L-1 | 1 | 19:03:30 | 3.45 | 1.39 | 1.72 | 1.60 | 1.86 | 1.66 |
| 1L-1 | 2 | 19:04:30 | 3.45 | 1.39 | 1.85 | 1.74 | 1.99 | 1.79 |
| 1L-1 | 4 | 19:06:30 | 3.45 | 1.39 | 2.03 | 1.94 | 2.21 | 1.99 |
| 1L-1 | 8 | 19:10:30 | 3.45 | 1.39 | 2.21 | 2.17 | 2.42 | 2.19 |
| 1L-2 | 1 | 19:12:00 | 6.89 | 2.76 | 4.16 | 3.96 | 4.36 | 4.06 |
| 1L-2 | 2 | 19:13:00 | 6.89 | 2.76 | 4.72 | 4.52 | 5.02 | 4.62 |
| 1L-2 | 4 | 19:15:00 | 6.89 | 2.76 | 5.43 | 5.28 | 5.78 | 5.36 |
| 1L-2 | 8 | 19:19:00 | 6.89 | 2.76 | 6.33 | 6.19 | 6.68 | 6.26 |
| 1L-3 | 1 | 19:21:30 | 10.34 | 4.13 | 8.72 | 8.52 | 9.13 | 8.62 |
| 1L-3 | 2 | 19:22:30 | 10.34 | 4.13 | 9.42 | 9.21 | 9.83 | 9.32 |
| 1L-3 | 4 | 19:24:30 | 10.34 | 4.13 | 10.39 | 10.20 | 10.90 | 10.29 |
| 1L-3 | 8 | 19:28:30 | 10.34 | 4.13 | 11.41 | 11.34 | 11.98 | 11.37 |
| 1L-4 | 1 | 19:30:30 | 13.79 | 5.49 | 15.42 | 15.11 | 15.90 | 15.27 |
| 1L-4 | 2 | 19:31:30 | 13.79 | 5.49 | 16.28 | 16.00 | 16.80 | 16.14 |
| 1L-4 | 4 | 19:33:30 | 13.79 | 5.49 | 17.63 | 17.28 | 18.11 | 17.46 |
| 1L-4 | 8 | 19:37:30 | 13.79 | 5.49 | 19.32 | 18.99 | 19.80 | 19.16 |
| 1L-5 | 1 | 19:39:30 | 17.24 | 6.86 | 25.46 | 25.04 | 26.09 | 25.25 |
| 1L-5 | 2 | 19:40:30 | 17.24 | 6.86 | 27.19 | 26.76 | 27.79 | 26.97 |
| 1L-5 | 4 | 19:42:30 | 17.24 | 6.86 | 29.49 | 29.14 | 30.18 | 29.31 |
| 1L-5 | 8 | 19:46:30 | 17.24 | 6.86 | 33.09 | 32.62 | 33.64 | 32.85 |
| 1L-6 | 1 | 19:49:00 | 19.86 | 7.90 | 42.68 | 42.13 | 43.39 | 42.40 |
| 1L-6 | 2 | 19:50:00 | 19.86 | 7.90 | 46.75 | 46.21 | 47.50 | 46.48 |
| 1L-6 | 4 | 19:52:00 | 19.86 | 7.90 | 54.38 | 53.85 | 55.18 | 54.12 |
| 1L-6 | 8 | 19:56:00 | 19.86 | 7.90 | 72.41 | 71.79 | 73.17 | 72.10 |
| 1U-1 | 1 | 19:58:00 | 13.79 | 5.49 | 72.23 | 71.52 | 73.16 | 71.88 |
| 1U-1 | 2 | 19:59:00 | 13.79 | 5.49 | 72.23 | 71.53 | 73.16 | 71.88 |
| 1U-1 | 4 | 20:01:00 | 13.79 | 5.49 | 72.24 | 71.55 | 73.17 | 71.89 |
| 1U-2 | 1 | 20:02:30 | 6.89 | 2.76 | 69.56 | 68.95 | 70.55 | 69.25 |
| 1U-2 | 2 | 20:03:30 | 6.89 | 2.76 | 69.39 | 68.77 | 70.31 | 69.08 |
| 1U-2 | 4 | 20:05:30 | 6.89 | 2.76 | 69.22 | 68.61 | 70.21 | 68.92 |
| 1U-3 | 1 | 20:07:00 | 3.45 | 1.39 | 66.86 | 66.37 | 67.98 | 66.62 |
| 1U-3 | 2 | 20:08:00 | 3.45 | 1.39 | 66.56 | 66.03 | 67.62 | 66.30 |
| 1U-3 | 4 | 20:10:00 | 3.45 | 1.39 | 66.20 | 65.67 | 67.10 | 65.93 |
| 1U-4 | 1 | 20:12:00 | 0.00 | 0.00 | 62.59 | 62.31 | 63.50 | 62.45 |
| 1U-4 | 2 | 20:13:00 | 0.00 | 0.00 | 61.84 | 61.55 | 62.78 | 61.69 |
| 1U-4 | 4 | 20:15:00 | 0.00 | 0.00 | 61.03 | 60.79 | 62.03 | 60.91 |
| 1U-4 | 8 | 20:19:00 | 0.00 | 0.00 | 60.20 | 59.93 | 61.14 | 60.06 |
| 1U-4 | 16 | 20:27:00 | 0.00 | 0.00 | 59.30 | 59.04 | 60.24 | 59.17 |

* LVWDT 18014 is a redundent instrument and is not included in the average.

## Upward and Downward O-cell™ Plate Movement
## West Test Shaft - US 36 over Republican River - Republic Co., KS

| Load Test Increment | Hold Time (minutes) | Time (h:m:s) | O-cell™ Pressure (MPa) | O-cell™ Load (MN) | TOS Movement (mm) | Total Compression (mm) | Upward Movement (mm) | O-cell™ Expansion (mm) | Downward Movement (mm) |
|---|---|---|---|---|---|---|---|---|---|
| 1L-0 | - | 18:51:00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1L-1 | 1 | 19:03:30 | 3.45 | 1.39 | 0.23 | 0.01 | 0.24 | 1.66 | 1.42 |
| 1L-1 | 2 | 19:04:30 | 3.45 | 1.39 | 0.23 | 0.01 | 0.25 | 1.79 | 1.55 |
| 1L-1 | 4 | 19:06:30 | 3.45 | 1.39 | 0.26 | 0.01 | 0.27 | 1.99 | 1.72 |
| 1L-1 | 8 | 19:10:30 | 3.45 | 1.39 | 0.29 | 0.01 | 0.30 | 2.19 | 1.89 |
| 1L-2 | 1 | 19:12:00 | 6.89 | 2.76 | 0.54 | 0.03 | 0.57 | 4.06 | 3.49 |
| 1L-2 | 2 | 19:13:00 | 6.89 | 2.76 | 0.60 | 0.04 | 0.63 | 4.62 | 3.98 |
| 1L-2 | 4 | 19:15:00 | 6.89 | 2.76 | 0.65 | 0.04 | 0.69 | 5.36 | 4.66 |
| 1L-2 | 8 | 19:19:00 | 6.89 | 2.76 | 0.75 | 0.04 | 0.79 | 6.26 | 5.47 |
| 1L-3 | 1 | 19:21:30 | 10.34 | 4.13 | 1.17 | 0.07 | 1.24 | 8.62 | 7.39 |
| 1L-3 | 2 | 19:22:30 | 10.34 | 4.13 | 1.30 | 0.07 | 1.37 | 9.32 | 7.95 |
| 1L-3 | 4 | 19:24:30 | 10.34 | 4.13 | 1.47 | 0.07 | 1.54 | 10.29 | 8.75 |
| 1L-3 | 8 | 19:28:30 | 10.34 | 4.13 | 1.66 | 0.08 | 1.74 | 11.37 | 9.64 |
| 1L-4 | 1 | 19:30:30 | 13.79 | 5.49 | 3.08 | 0.11 | 3.19 | 15.27 | 12.07 |
| 1L-4 | 2 | 19:31:30 | 13.79 | 5.49 | 3.41 | 0.11 | 3.53 | 16.14 | 12.62 |
| 1L-4 | 4 | 19:33:30 | 13.79 | 5.49 | 3.90 | 0.11 | 4.02 | 17.46 | 13.44 |
| 1L-4 | 8 | 19:37:30 | 13.79 | 5.49 | 4.46 | 0.12 | 4.58 | 19.16 | 14.58 |
| 1L-5 | 1 | 19:39:30 | 17.24 | 6.86 | 7.83 | 0.14 | 7.97 | 25.25 | 17.28 |
| 1L-5 | 2 | 19:40:30 | 17.24 | 6.86 | 8.85 | 0.14 | 9.00 | 26.97 | 17.98 |
| 1L-5 | 4 | 19:42:30 | 17.24 | 6.86 | 10.19 | 0.14 | 10.34 | 29.31 | 18.98 |
| 1L-5 | 8 | 19:46:30 | 17.24 | 6.86 | 12.06 | 0.14 | 12.20 | 32.85 | 20.65 |
| 1L-6 | 1 | 19:49:00 | 19.86 | 7.90 | 18.59 | 0.17 | 18.75 | 42.40 | 23.65 |
| 1L-6 | 2 | 19:50:00 | 19.86 | 7.90 | 21.68 | 0.17 | 21.85 | 46.48 | 24.63 |
| 1L-6 | 4 | 19:52:00 | 19.86 | 7.90 | 27.85 | 0.17 | 28.02 | 54.12 | 26.10 |
| 1L-6 | 8 | 19:56:00 | 19.86 | 7.90 | 43.42 | 0.18 | 43.60 | 72.10 | 28.49 |
| 1U-1 | 1 | 19:58:00 | 13.79 | 5.49 | 44.24 | 0.15 | 44.39 | 71.88 | 27.49 |
| 1U-1 | 2 | 19:59:00 | 13.79 | 5.49 | 44.23 | 0.15 | 44.37 | 71.88 | 27.51 |
| 1U-1 | 4 | 20:01:00 | 13.79 | 5.49 | 44.18 | 0.15 | 44.33 | 71.89 | 27.56 |
| 1U-2 | 1 | 20:02:30 | 6.89 | 2.76 | 43.44 | 0.08 | 43.51 | 69.25 | 25.74 |
| 1U-2 | 2 | 20:03:30 | 6.89 | 2.76 | 43.38 | 0.07 | 43.46 | 69.08 | 25.62 |
| 1U-2 | 4 | 20:05:30 | 6.89 | 2.76 | 43.32 | 0.07 | 43.39 | 68.92 | 25.53 |
| 1U-3 | 1 | 20:07:00 | 3.45 | 1.39 | 42.79 | 0.03 | 42.83 | 66.62 | 23.79 |
| 1U-3 | 2 | 20:08:00 | 3.45 | 1.39 | 42.72 | 0.03 | 42.75 | 66.30 | 23.55 |
| 1U-3 | 4 | 20:10:00 | 3.45 | 1.39 | 42.62 | 0.03 | 42.65 | 65.93 | 23.28 |
| 1U-4 | 1 | 20:12:00 | 0.00 | 0.00 | 41.89 | -0.02 | 41.88 | 62.45 | 20.57 |
| 1U-4 | 2 | 20:13:00 | 0.00 | 0.00 | 41.76 | -0.02 | 41.74 | 61.69 | 19.95 |
| 1U-4 | 4 | 20:15:00 | 0.00 | 0.00 | 41.62 | -0.02 | 41.59 | 60.91 | 19.31 |
| 1U-4 | 8 | 20:19:00 | 0.00 | 0.00 | 41.50 | -0.02 | 41.48 | 60.06 | 18.59 |
| 1U-4 | 16 | 20:27:00 | 0.00 | 0.00 | 41.36 | -0.03 | 41.33 | 59.17 | 17.84 |

## Upward and Downward Creep
## West Test Shaft - US 36 over Republican River - Republic Co., KS

| Load Test Increment | Hold Time (minutes) | Time (h:m:s) | O-cell™ Pressure (MPa) | O-cell™ Load (MN) | Upward Movement (mm) | Creep Between Hold (mm) | Downward Movement (mm) | Creep Between Hold (mm) |
|---|---|---|---|---|---|---|---|---|
| 1 L - 0 | - | 18:51:00 | 0.00 | 0.00 | 0.00 | | 0.00 | |
| 1 L - 1 | 1 | 19:03:30 | 3.45 | 1.39 | 0.24 | | 1.42 | |
| 1 L - 1 | 2 | 19:04:30 | 3.45 | 1.39 | 0.25 | 0.00 | 1.55 | 0.13 |
| 1 L - 1 | 4 | 19:06:30 | 3.45 | 1.39 | 0.27 | 0.02 | 1.72 | 0.17 |
| 1 L - 1 | 8 | 19:10:30 | 3.45 | 1.39 | 0.30 | 0.03 | 1.89 | 0.17 |
| 1 L - 2 | 1 | 19:12:00 | 6.89 | 2.76 | 0.57 | | 3.49 | |
| 1 L - 2 | 2 | 19:13:00 | 6.89 | 2.76 | 0.63 | 0.07 | 3.98 | 0.49 |
| 1 L - 2 | 4 | 19:15:00 | 6.89 | 2.76 | 0.69 | 0.06 | 4.66 | 0.68 |
| 1 L - 2 | 8 | 19:19:00 | 6.89 | 2.76 | 0.79 | 0.09 | 5.47 | 0.81 |
| 1 L - 3 | 1 | 19:21:30 | 10.34 | 4.13 | 1.24 | | 7.39 | |
| 1 L - 3 | 2 | 19:22:30 | 10.34 | 4.13 | 1.37 | 0.13 | 7.95 | 0.56 |
| 1 L - 3 | 4 | 19:24:30 | 10.34 | 4.13 | 1.54 | 0.17 | 8.75 | 0.80 |
| 1 L - 3 | 8 | 19:28:30 | 10.34 | 4.13 | 1.74 | 0.20 | 9.64 | 0.88 |
| 1 L - 4 | 1 | 19:30:30 | 13.79 | 5.49 | 3.19 | | 12.07 | |
| 1 L - 4 | 2 | 19:31:30 | 13.79 | 5.49 | 3.53 | 0.33 | 12.62 | 0.54 |
| 1 L - 4 | 4 | 19:33:30 | 13.79 | 5.49 | 4.02 | 0.49 | 13.44 | 0.82 |
| 1 L - 4 | 8 | 19:37:30 | 13.79 | 5.49 | 4.58 | 0.57 | 14.58 | 1.14 |
| 1 L - 5 | 1 | 19:39:30 | 17.24 | 6.86 | 7.97 | | 17.28 | |
| 1 L - 5 | 2 | 19:40:30 | 17.24 | 6.86 | 9.00 | 1.03 | 17.98 | 0.70 |
| 1 L - 5 | 4 | 19:42:30 | 17.24 | 6.86 | 10.34 | 1.34 | 18.98 | 1.00 |
| 1 L - 5 | 8 | 19:46:30 | 17.24 | 6.86 | 12.20 | 1.86 | 20.65 | 1.68 |
| 1 L - 6 | 1 | 19:49:00 | 19.86 | 7.90 | 18.75 | | 23.65 | |
| 1 L - 6 | 2 | 19:50:00 | 19.86 | 7.90 | 21.85 | | 24.63 | |
| 1 L - 6 | 4 | 19:52:00 | 19.86 | 7.90 | 28.02 | | 26.10 | |
| 1 L - 6 | 8 | 19:56:00 | 19.86 | 7.90 | 43.60 | | 28.49 | |
| 1 U - 1 | 1 | 19:58:00 | 13.79 | 5.49 | 44.39 | | 27.49 | |
| 1 U - 1 | 2 | 19:59:00 | 13.79 | 5.49 | 44.37 | | 27.51 | |
| 1 U - 1 | 4 | 20:01:00 | 13.79 | 5.49 | 44.33 | | 27.56 | |
| 1 U - 2 | 1 | 20:02:30 | 6.89 | 2.76 | 43.51 | | 25.74 | |
| 1 U - 2 | 2 | 20:03:30 | 6.89 | 2.76 | 43.46 | | 25.62 | |
| 1 U - 2 | 4 | 20:05:30 | 6.89 | 2.76 | 43.39 | | 25.53 | |
| 1 U - 3 | 1 | 20:07:00 | 3.45 | 1.39 | 42.83 | | 23.79 | |
| 1 U - 3 | 2 | 20:08:00 | 3.45 | 1.39 | 42.75 | | 23.55 | |
| 1 U - 3 | 4 | 20:10:00 | 3.45 | 1.39 | 42.65 | | 23.28 | |
| 1 U - 4 | 1 | 20:12:00 | 0.00 | 0.00 | 41.88 | | 20.57 | |
| 1 U - 4 | 2 | 20:13:00 | 0.00 | 0.00 | 41.74 | | 19.95 | |
| 1 U - 4 | 4 | 20:15:00 | 0.00 | 0.00 | 41.59 | | 19.31 | |
| 1 U - 4 | 8 | 20:19:00 | 0.00 | 0.00 | 41.48 | | 18.59 | |
| 1 U - 4 | 16 | 20:27:00 | 0.00 | 0.00 | 41.33 | | 17.84 | |

.25

5.49

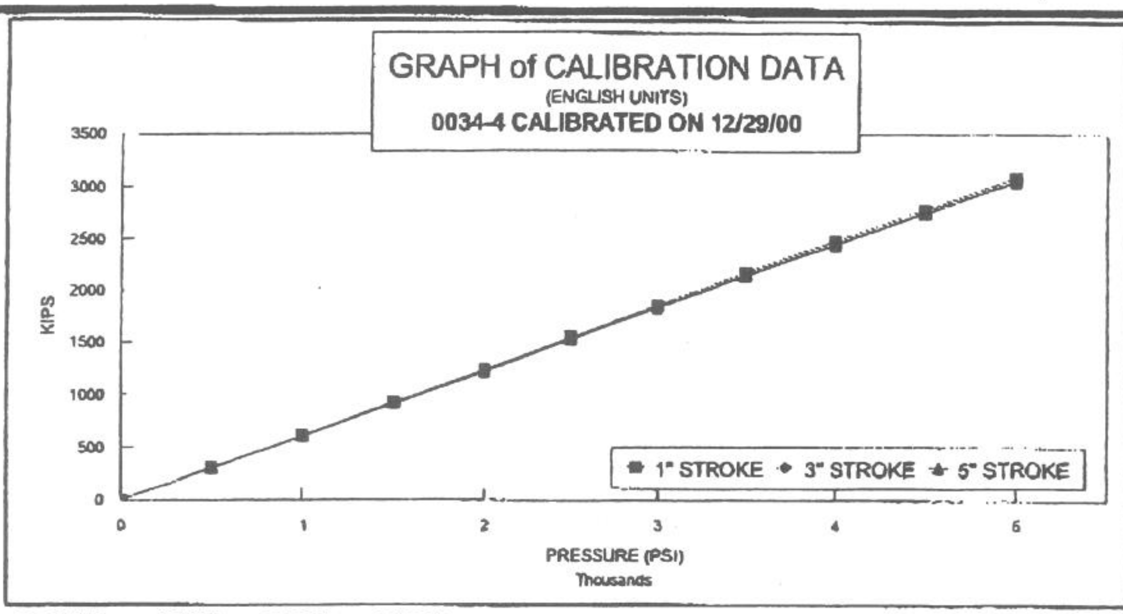
5.49
2.76

## Strain Gage Readings and Loads at Levels 1 and 2
## West Test Shaft - US 36 over Republican River - Republic Co., KS

| Load Test Increment | Hold Time (minutes) | Time (h:m:s) | O-cell™ Pressure (MPa) | O-cell™ Load (MN) | Level 1 20357 (με) | Level 1 20358 (με) | Level 1 20359 (με) | Level 1 20360 (με) | Level 1 Av. Load (MN) | Level 2 20365 (με) | Level 2 20366 (με) | Level 2 20367 (με) | Level 2 20368 (με) | Level 2 Av. Load (MN) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 L - 0 | - | 18:51:00 | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 |
| 1 L - 1 | 1 | 19:03:30 | 3.45 | 1.39 | 5.7 | 8.3 | 5.3 | 2.4 | 0.41 | 1.5 | 1.7 | 1.3 | 1.0 | 0.10 |
| 1 L - 1 | 2 | 19:04:30 | 3.45 | 1.39 | 5.7 | 8.8 | 5.4 | 2.5 | 0.43 | 1.6 | 1.8 | 1.4 | 1.0 | 0.11 |
| 1 L - 1 | 4 | 19:06:30 | 3.45 | 1.39 | 6.2 | 9.1 | 5.9 | 2.7 | 0.45 | 1.6 | 1.8 | 1.5 | 1.1 | 0.12 |
| 1 L - 1 | 8 | 19:10:30 | 3.45 | 1.39 | 6.3 | 9.1 | 5.9 | 3.3 | 0.47 | 1.7 | 1.9 | 1.5 | 1.9 | 0.13 |
| 1 L - 2 | 1 | 19:12:00 | 6.89 | 2.76 | 12.0 | 16.1 | 10.9 | 6.9 | 0.88 | 2.7 | 3.5 | 2.6 | 2.8 | 0.22 |
| 1 L - 2 | 2 | 19:13:00 | 6.89 | 2.76 | 13.1 | 17.0 | 11.4 | 7.6 | 0.94 | 2.8 | 3.4 | 2.8 | 2.7 | 0.22 |
| 1 L - 2 | 4 | 19:15:00 | 6.89 | 2.76 | 14.0 | 17.6 | 12.1 | 8.3 | 0.99 | 3.0 | 3.7 | 3.0 | 3.5 | 0.25 |
| 1 L - 2 | 8 | 19:19:00 | 6.89 | 2.76 | 14.6 | 19.1 | 13.0 | 9.0 | 1.06 | 3.3 | 3.7 | 3.2 | 3.4 | 0.26 |
| 1 L - 3 | 1 | 19:21:30 | 10.34 | 4.13 | 22.1 | 27.2 | 18.4 | 13.8 | 1.56 | 4.5 | 5.0 | 4.4 | 5.0 | 0.36 |
| 1 L - 3 | 2 | 19:22:30 | 10.34 | 4.13 | 23.0 | 27.7 | 19.3 | 15.0 | 1.63 | 4.9 | 4.9 | 4.5 | 5.8 | 0.38 |
| 1 L - 3 | 4 | 19:24:30 | 10.34 | 4.13 | 23.8 | 28.8 | 20.4 | 16.2 | 1.71 | 5.1 | 4.9 | 4.7 | 5.5 | 0.39 |
| 1 L - 3 | 8 | 19:28:30 | 10.34 | 4.13 | 24.3 | 29.2 | 20.7 | 16.7 | 1.74 | 5.2 | 4.7 | 4.7 | 5.8 | 0.39 |
| 1 L - 4 | 1 | 19:30:30 | 13.79 | 5.49 | 32.9 | 37.5 | 26.1 | 22.2 | 2.27 | 6.3 | 5.2 | 5.5 | 6.4 | 0.45 |
| 1 L - 4 | 2 | 19:31:30 | 13.79 | 5.49 | 33.3 | 38.0 | 26.6 | 22.9 | 2.31 | 6.7 | 5.3 | 5.7 | 6.3 | 0.46 |
| 1 L - 4 | 4 | 19:33:30 | 13.79 | 5.49 | 33.3 | 37.9 | 26.6 | 23.0 | 2.31 | 6.6 | 5.0 | 5.9 | 6.1 | 0.45 |
| 1 L - 4 | 8 | 19:37:30 | 13.79 | 5.49 | 33.5 | 38.0 | 26.9 | 23.5 | 2.33 | 6.8 | 5.2 | 6.1 | 5.8 | 0.46 |
| 1 L - 5 | 1 | 19:39:30 | 17.24 | 6.86 | 40.6 | 44.2 | 30.5 | 27.9 | 2.74 | 5.9 | 6.8 | 7.6 | 7.3 | 0.53 |
| 1 L - 5 | 2 | 19:40:30 | 17.24 | 6.86 | 40.6 | 44.3 | 30.6 | 28.5 | 2.75 | 5.8 | 7.4 | 7.9 | 7.2 | 0.54 |
| 1 L - 5 | 4 | 19:42:30 | 17.24 | 6.86 | 40.5 | 44.3 | 31.2 | 29.2 | 2.77 | 5.9 | 8.2 | 9.0 | 7.3 | 0.58 |
| 1 L - 5 | 8 | 19:46:30 | 17.24 | 6.86 | 40.6 | 44.2 | 31.4 | 30.2 | 2.80 | 6.2 | 9.4 | 10.4 | 8.0 | 0.65 |
| 1 L - 6 | 1 | 19:49:00 | 19.86 | 7.90 | 45.1 | 45.5 | 34.0 | 35.3 | 3.06 | 3.9 | 14.0 | 13.5 | 8.6 | 0.76 |
| 1 L - 6 | 2 | 19:50:00 | 19.86 | 7.90 | 45.1 | 46.4 | 35.4 | 36.1 | 3.12 | 3.9 | 15.2 | 14.6 | 8.4 | 0.81 |
| 1 L - 6 | 4 | 19:52:00 | 19.86 | 7.90 | 43.0 | 45.4 | 37.3 | 36.4 | 3.10 | 4.0 | 16.8 | 14.9 | 8.4 | 0.85 |
| 1 L - 6 | 8 | 19:56:00 | 19.86 | 7.90 | 36.5 | 45.7 | 42.4 | 34.8 | 3.05 | 4.3 | 21.8 | 13.7 | 6.7 | 0.89 |
| 1 U - 1 | 1 | 19:58:00 | 13.79 | 5.49 | 25.1 | 32.9 | 32.5 | 25.2 | 2.22 | 0.8 | 16.5 | 9.8 | 3.1 | 0.58 |
| 1 U - 1 | 2 | 19:59:00 | 13.79 | 5.49 | 25.0 | 33.6 | 32.3 | 25.2 | 2.22 | 0.8 | 15.6 | 9.8 | 3.3 | 0.56 |
| 1 U - 1 | 4 | 20:01:00 | 13.79 | 5.49 | 24.2 | 32.0 | 32.0 | 25.1 | 2.17 | 0.8 | 14.7 | 9.5 | 3.4 | 0.54 |
| 1 U - 2 | 1 | 20:02:30 | 6.89 | 2.76 | 9.7 | 15.0 | 18.1 | 14.3 | 1.09 | -5.5 | 8.3 | 4.4 | -0.9 | 0.12 |
| 1 U - 2 | 2 | 20:03:30 | 6.89 | 2.76 | 9.2 | 13.8 | 18.0 | 14.4 | 1.06 | -5.3 | 8.0 | 4.3 | -0.8 | 0.12 |
| 1 U - 2 | 4 | 20:05:30 | 6.89 | 2.76 | 9.3 | 13.7 | 18.3 | 14.4 | 1.07 | -5.6 | 7.5 | 4.3 | -0.7 | 0.10 |
| 1 U - 3 | 1 | 20:07:00 | 3.45 | 1.39 | 0.2 | 2.8 | 11.1 | 8.6 | 0.44 | -9.0 | 2.7 | 1.5 | -3.9 | -0.16 |
| 1 U - 3 | 2 | 20:08:00 | 3.45 | 1.39 | -0.4 | 2.4 | 10.6 | 8.5 | 0.41 | -9.2 | 2.9 | 1.4 | -3.6 | -0.16 |
| 1 U - 3 | 4 | 20:10:00 | 3.45 | 1.39 | -0.8 | 2.1 | 10.4 | 8.4 | 0.38 | -9.3 | 2.5 | 1.2 | -3.9 | -0.18 |
| 1 U - 4 | 1 | 20:12:00 | 0.00 | 0.00 | -9.1 | -8.7 | 3.3 | 4.0 | -0.20 | -12.8 | -2.7 | -1.3 | -6.4 | -0.44 |
| 1 U - 4 | 2 | 20:13:00 | 0.00 | 0.00 | -9.7 | -9.1 | 2.9 | 3.3 | -0.24 | -12.9 | -3.1 | -1.4 | -6.6 | -0.46 |
| 1 U - 4 | 4 | 20:15:00 | 0.00 | 0.00 | -10.0 | -9.4 | 3.1 | 3.0 | -0.25 | -13.2 | -3.5 | -1.5 | -6.8 | -0.48 |
| 1 U - 4 | 8 | 20:19:00 | 0.00 | 0.00 | -10.3 | -9.5 | 2.7 | 3.1 | -0.27 | -13.2 | -3.8 | -1.6 | -6.6 | -0.48 |
| 1 U - 4 | 16 | 20:27:00 | 0.00 | 0.00 | -10.4 | -9.7 | 2.5 | 2.9 | -0.28 | -13.6 | -4.1 | -1.7 | -6.7 | -0.50 |

# APPENDIX B

## O-CELL™ AND INSTRUMENTATION CALIBRATION SHEETS




| STROKE: | 1 INCH | 3 INCH | 5 INCH |
|---|---|---|---|
| PRESSURE PSI | LOAD KIPS | LOAD KIPS | LOAD KIPS |
| 0 | 0 | 0 | 0 |
| 500 | 311 | 306 | 305 |
| 1000 | 622 | 616 | 614 |
| 1500 | 942 | 929 | 923 |
| 2000 | 1251 | 1235 | 1227 |
| 2500 | 1560 | 1544 | 1535 |
| 3000 | 1867 | 1848 | 1839 |
| 3500 | 2178 | 2156 | 2145 |
| 4000 | 2485 | 2458 | 2448 |
| 4500 | 2792 | 2771 | 2755 |
| 5000 | 3095 | 3073 | 3056 |

**34" O-CELL, SERIAL # 0034-4**

**LOAD CONVERSION FORMULA**

**LOAD = PRESSURE * 0.6149 + ( 5.13 )**
(KIPS) (PSI)

**Regression Output:**

| | |
|---|---|
| Constant | 5.135 |
| X Coefficient | 0.615 |
| R Squared | 1.000 |
| No. of Observations | 30 |
| Degrees of Freedom | 28 |
| Std Err of Y Est | 12.356 |
| Std Err of X Coef. | 0.002 |

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: MIDWEST FOUNDATION |
| *AE & FC JOB NO.: 1806 | *JOB LOCATION: TOPEKA, KS |
| *CUSTOMER P.O.NO.: LT-8718 | *DATED: 03/08/01 |

SERVICE ENGINEER: [signature] DATE: 3/15/01

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

# Vibrating Wire Displacement Transducer Calibration Report

Model Number: 4450-3-6

Range: 6"

Serial Number: 18012

Mfg. Number: 01-219

Customer: Loadtest, Inc.

Temperature: 23.9 °C

Cust. I.D. #: n/a

Cal. Std. Control #(s): 124, 249, 406, 524, 529

Job Number: 16668

Date of Calibration: March 05, 2001

Technician: TDB

| Displacement (inches) | GK-401 Reading Position B Cycle 1 | Cycle 2 | Average | Change | % Linearity |
|---|---|---|---|---|---|
| 0.000 | 2705 | 2703 | 2704 | | -0.20 |
| 1.200 | 3967 | 3964 | 3966 | 1262 | 0.10 |
| 2.400 | 5213 | 5212 | 5213 | 1247 | 0.16 |
| 3.600 | 6449 | 6448 | 6449 | 1236 | 0.05 |
| 4.800 | 7691 | 7689 | 7690 | 1242 | 0.02 |
| 6.000 | 8923 | 8923 | 8923 | 1233 | -0.14 |

**Calibration Factor (C): 0.0009654 (Inches/Digit)**

**Regression Zero: 2716**

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

Function Test at Shipment (GK-401 Reading)

Position "B":* 5548

or

Position "F":* ______

Date: March 13, 2001

Temperature: 24.9 °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: 18013 | Mfg. Number: 01-220

Customer: Loadtest, Inc. | Temperature: 23.9 °C

Cust. I.D. #: n/a | Cal. Std. Control #(s): 124, 249, 406, 524, 529

Job Number: 16668 | Date of Calibration: March 05, 2001

Technician: KDB

| Displacement (inches) | GK-401 Reading Position B Cycle 1 | Cycle 2 | Average | Change | % Linearity |
|---|---|---|---|---|---|
| 0.000 | 2710 | 2706 | 2708 | | -0.22 |
| 1.200 | 3961 | 3959 | 3960 | 1252 | 0.08 |
| 2.400 | 5201 | 5198 | 5200 | 1240 | 0.17 |
| 3.600 | 6433 | 6429 | 6431 | 1232 | 0.13 |
| 4.800 | 7659 | 7656 | 7658 | 1227 | 0.01 |
| 6.000 | 8881 | 8880 | 8881 | 1223 | -0.17 |

**Calibration Factor (C): 0.0009725 (Inches/Digit)**

**Regression Zero: 2721**

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

Function Test at Shipment (GK-401 Reading)

Position "B":* 5492 | Date: March 13, 2001

or

Position "F":* | Temperature: 26.3 °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: 18014

Mfg. Number: 01-221

Customer: Loadtest, Inc.

Temperature: 23.9 °C

Cust. I.D. #: n/a

Cal. Std. Control #(s): 124, 249, 406, 524, 529

Job Number: 16668

Date of Calibration: March 05, 2001

Technician: KDB

| Displacement (inches) | GK-401 Reading Position B Cycle 1 | Cycle 2 | Average | Change | % Linearity |
|---|---|---|---|---|---|
| 0.000 | 2715 | 2712 | 2714 | | -0.20 |
| 1.200 | 3965 | 3963 | 3964 | 1251 | 0.09 |
| 2.400 | 5200 | 5200 | 5200 | 1236 | 0.15 |
| 3.600 | 6430 | 6428 | 6429 | 1229 | 0.10 |
| 4.800 | 7656 | 7653 | 7655 | 1226 | -0.01 |
| 6.000 | 8880 | 8878 | 8879 | 1225 | -0.14 |

**Calibration Factor (C): 0.0009738 (Inches/Digit)**

**Regression Zero: 2726**

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

Function Test at Shipment (GK-401 Reading)

Position "B":* 5528

or

Position "F":* ______

Date: March 13, 2001

Temperature: 23.6 °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: 20357

Customer: Loadtest, Inc.

Job Number: 16668

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 22.0 °C

Calibration Date: March 13, 2001

Cal. Std. Control Numbers: 85888-1, 398

Cable Length: 40'

Factory Zero Reading: 6681

Regression Zero: 6695

Technician: KDB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 6748 | 6750 | 6749 | | |
| 1,500 | 7433 | 7428 | 7431 | 682 | -0.20 |
| 3,000 | 8179 | 8174 | 8177 | 746 | -0.05 |
| 4,500 | 8927 | 8918 | 8923 | 746 | 0.11 |
| 6,000 | 9663 | 9658 | 9661 | 738 | -0.01 |
| 100 | 6755 | | | | |

*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 per cent

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: 20358

Customer: Loadtest, Inc.

Job Number: 16668

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 22.2 °C

Calibration Date: March 13, 2001

Cal. Std. Control Numbers: 85888-1, 398

Cable Length: 40'

Factory Zero Reading: 7036

Regression Zero: 7050

Technician: KRB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 7101 | 7101 | 7101 | | |
| 1,500 | 7777 | 7768 | 7773 | 672 | -0.12 |
| 3,000 | 8501 | 8501 | 8501 | 729 | -0.03 |
| 4,500 | 9230 | 9229 | 9230 | 729 | 0.06 |
| 6,000 | 9954 | 9953 | 9954 | 724 | 0.00 |
| 100 | 7102 | | | | |

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

**Gage Factor:**

**0.348 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 per cent

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: 20359

Customer: Loadtest, Inc.

Job Number: 16668

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 21.7 °C

Calibration Date: March 13, 2001

Cal. Std. Control Numbers: 85888-1, 398

Cable Length: 40'

Factory Zero Reading: 7048

Regression Zero: 7048

Technician: KDB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 7103 | 7101 | 7102 | | |
| 1,500 | 7760 | 7754 | 7757 | 655 | -0.22 |
| 3,000 | 8476 | 8475 | 8476 | 719 | -0.11 |
| 4,500 | 9205 | 9193 | 9199 | 724 | 0.17 |
| 6,000 | 9909 | 9911 | 9910 | 711 | 0.01 |
| 100 | 7105 | | | | |

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

**Gage Factor:**

**0.352 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 per cent
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: 20360

Customer: Loadtest, Inc.

Job Number: 16668

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 22.2 °C

Calibration Date: March 13, 2001

Cal. Std. Control Numbers: 85888-1, 398

Cable Length: 40'

Factory Zero Reading: 7091

Regression Zero: 7108

Technician: KDB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 7161 | 7162 | 7162 | | |
| 1,500 | 7839 | 7834 | 7837 | 675 | -0.11 |
| 3,000 | 8572 | 8569 | 8571 | 734 | -0.03 |
| 4,500 | 9305 | 9303 | 9304 | 734 | 0.03 |
| 6,000 | 10039 | 10036 | 10038 | 734 | 0.09 |
| 100 | 7163 | | | | |

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

**Gage Factor:**

**0.346 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 per cent
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 | Calibration Date: | March 13, 2001 |
| Serial Number: | 20365 | Cal. Std. Control Numbers: | 85888-1, 398 |
| Customer: | Loadtest, Inc. | Cable Length: | 35' |
| Job Number: | 16668 | Factory Zero Reading: | 6635 |
| Cust. I.D. #: | n/a | Regression Zero: | 6656 |
| Prestress: | 35,000 psi | | |
| Temperature: | 22.3 °C | Technician: | KDB |

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 6714 | 6707 | 6711 | | |
| 1,500 | 7397 | 7389 | 7393 | 683 | -0.18 |
| 3,000 | 8143 | 8135 | 8139 | 746 | -0.06 |
| 4,500 | 8891 | 8887 | 8889 | 750 | 0.20 |
| 6,000 | 9629 | 9620 | 9625 | 736 | -0.03 |
| 100 | 6711 | | | | |

*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 per cent

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: 20366

Customer: Loadtest, Inc.

Job Number: 16668

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 22.0 °C

Calibration Date: March 13, 2001

Cal. Std. Control Numbers: 85888-1, 398

Cable Length: 35'

Factory Zero Reading: 6923

Regression Zero: 6928

Technician: KDB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 6980 | 6985 | 6983 | | |
| 1,500 | 7660 | 7661 | 7661 | 678 | -0.21 |
| 3,000 | 8406 | 8409 | 8408 | 747 | 0.08 |
| 4,500 | 9145 | 9147 | 9146 | 739 | 0.07 |
| 6,000 | 9884 | 9883 | 9884 | 738 | 0.03 |
| 100 | 6985 | | | | |

*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 per cent
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: 20367

Customer: Loadtest, Inc.

Job Number: 16668

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 22.9 °C

Calibration Date: March 13, 2001

Cal. Std. Control Numbers: 85888-1, 398

Cable Length: 35'

Factory Zero Reading: 6806

Regression Zero: 6817

Technician: KDB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 6872 | 6871 | 6872 | | |
| 1,500 | 7560 | 7556 | 7558 | 687 | -0.14 |
| 3,000 | 8306 | 8307 | 8307 | 749 | -0.03 |
| 4,500 | 9057 | 9055 | 9056 | 750 | 0.11 |
| 6,000 | 9798 | 9800 | 9799 | 743 | 0.03 |
| 100 | 6872 | | | | |

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

**Gage Factor:**

**0.342 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 per cent
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: 20368

Customer: Loadtest, Inc.

Job Number: 16668

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 22.8 °C

Calibration Date: March 13, 2001

Cal. Std. Control Numbers: 85888-1, 398

Cable Length: 35'

Factory Zero Reading: 6694

Regression Zero: 6697

Technician: KDB

| Applied Load: (pounds) | Readings | | | | Linearity % Max.Load |
|---|---|---|---|---|---|
| | Cycle #1 | Cycle #2 | Average | Change | |
| 100 | 6753 | 6753 | 6753 | | |
| 1,500 | 7437 | 7442 | 7440 | 687 | -0.23 |
| 3,000 | 8192 | 8198 | 8195 | 756 | -0.03 |
| 4,500 | 8951 | 8952 | 8952 | 757 | 0.21 |
| 6,000 | 9695 | 9693 | 9694 | 743 | -0.03 |
| 100 | 6755 | | | | |

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

**Gage Factor:**

**0.340 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 per cent
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 $\ell_3 = 0$. 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.

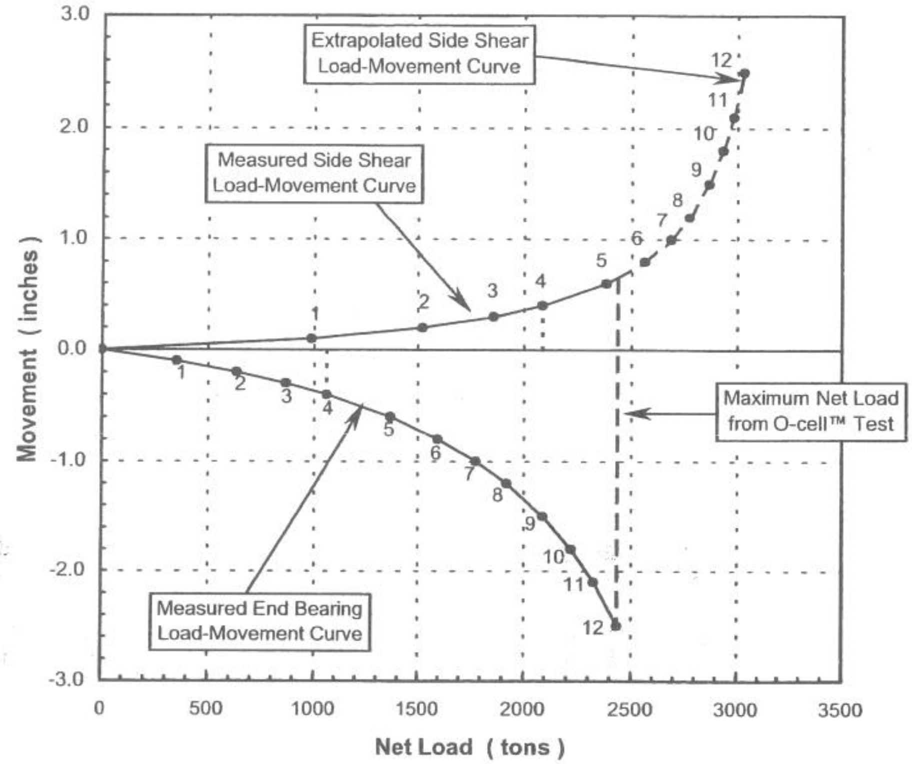
B. H. Fellenius has made several finite element method (FEM) studies of an OLT in which he adjusted the parameters to produce good load-deflection matches with the OLT up and down load-deflection curves. He then used the same parameters to predict the TLT deflection curve. We compared the FEM-predicted 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.

**Limitations:** 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.

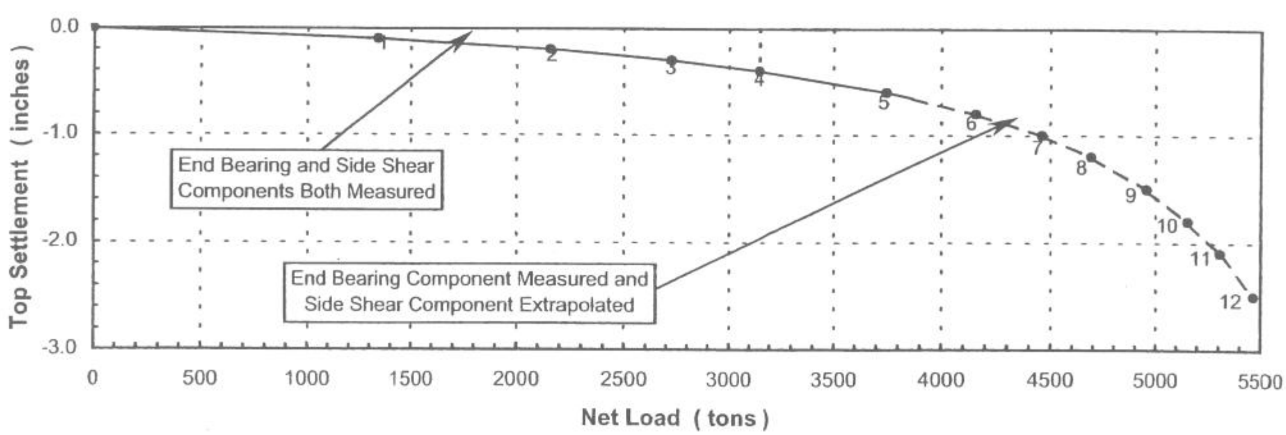
August, 2000

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

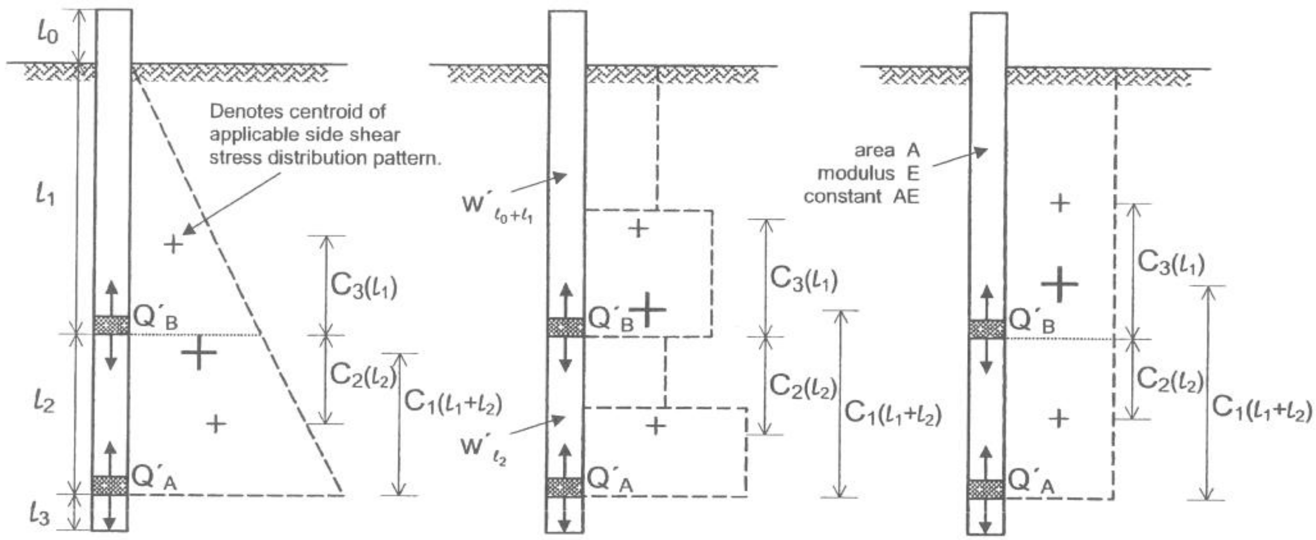
## Figure A




## 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):** $\delta_{OLT} = \delta_{\uparrow(\ell_1+\ell_2)}$

| | | |
|---|---|---|
| $C_1 = \frac{1}{3}$ | $\text{Centroid Factor} = C_1$ | $C_1 = \frac{1}{2}$ |
| $\delta_{\uparrow(\ell_1+\ell_2)} = \frac{1}{3}\frac{Q'_{\uparrow A}(\ell_1+\ell_2)}{AE}$ | $\delta_{\uparrow(\ell_1+\ell_2)} = C_1\frac{Q'_{\uparrow A}(\ell_1+\ell_2)}{AE}$ | $\delta_{\uparrow(\ell_1+\ell_2)} = \frac{1}{2}\frac{Q'_{\uparrow A}(\ell_1+\ell_2)}{AE}$ |

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

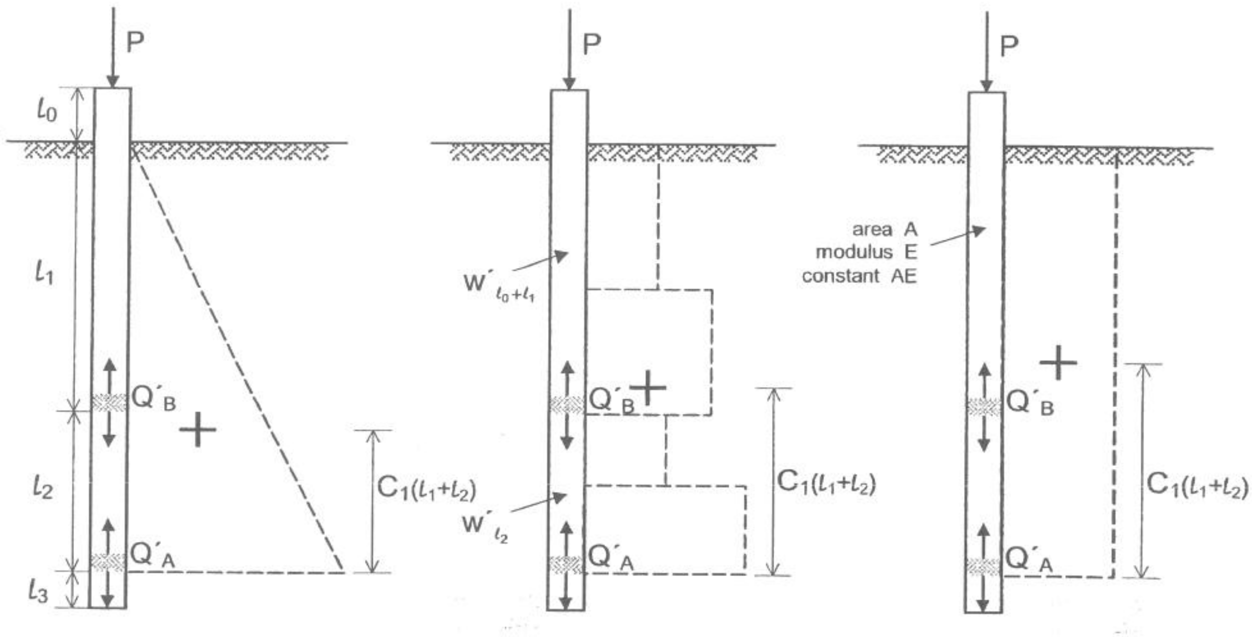
| | | |
|---|---|---|
| $C_3 = \frac{1}{3}$ | $\text{Centroid Factor} = C_3$ | $C_3 = \frac{1}{2}$ |
| $\delta_{\uparrow\ell_1} = \frac{1}{3}\frac{Q'_{\uparrow B}\ell_1}{AE}$ | $\delta_{\uparrow\ell_1} = C_3\frac{Q'_{\uparrow B}\ell_1}{AE}$ | $\delta_{\uparrow\ell_1} = \frac{1}{3}\frac{Q'_{\uparrow B}\ell_1}{AE}$ |
| $C_2 = \frac{1}{3}\left(\frac{3\ell_1+2\ell_2}{2\ell_1+\ell_2}\right)$ | $\text{Centroid Factor} = C_2$ | $C_2 = \frac{1}{2}$ |
| $\delta_{\downarrow\ell_2} = \frac{1}{3}\left(\frac{3\ell_1+2\ell_2}{2\ell_1+\ell_2}\right)\frac{Q'_{\downarrow B}\ell_2}{AE}$ | $\delta_{\downarrow\ell_2} = C_2\frac{Q'_{\downarrow B}\ell_2}{AE}$ | $\delta_{\downarrow\ell_2} = \frac{1}{2}\frac{Q'_{\downarrow B}\ell_2}{AE}$ |

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

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

**Net and Equivalent Loads:**

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

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

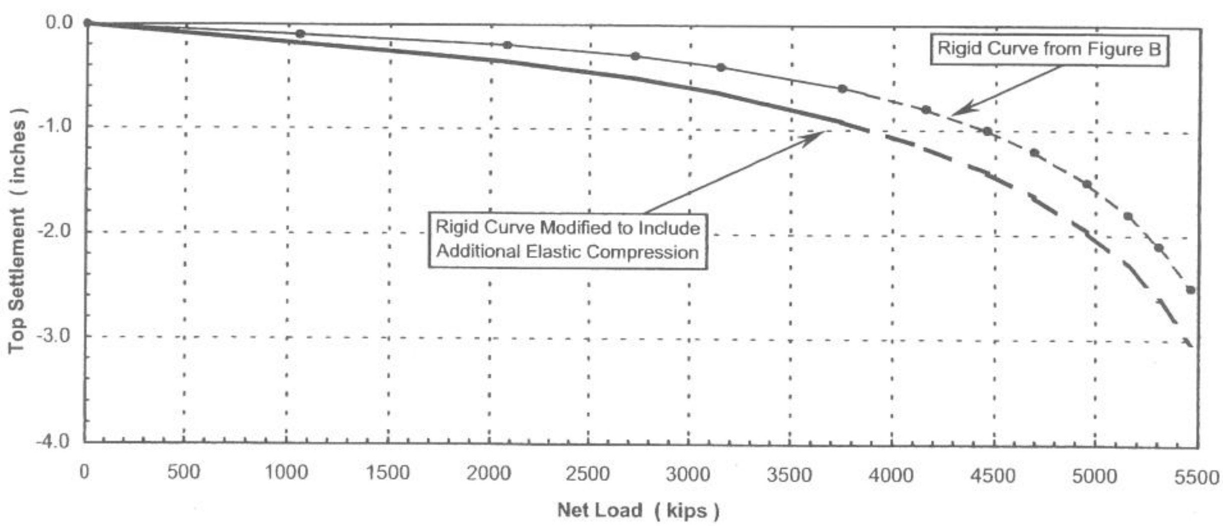
## Example Calcuation for the Additional Elastic Compression Correction for Single Level Test (English Units)

**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



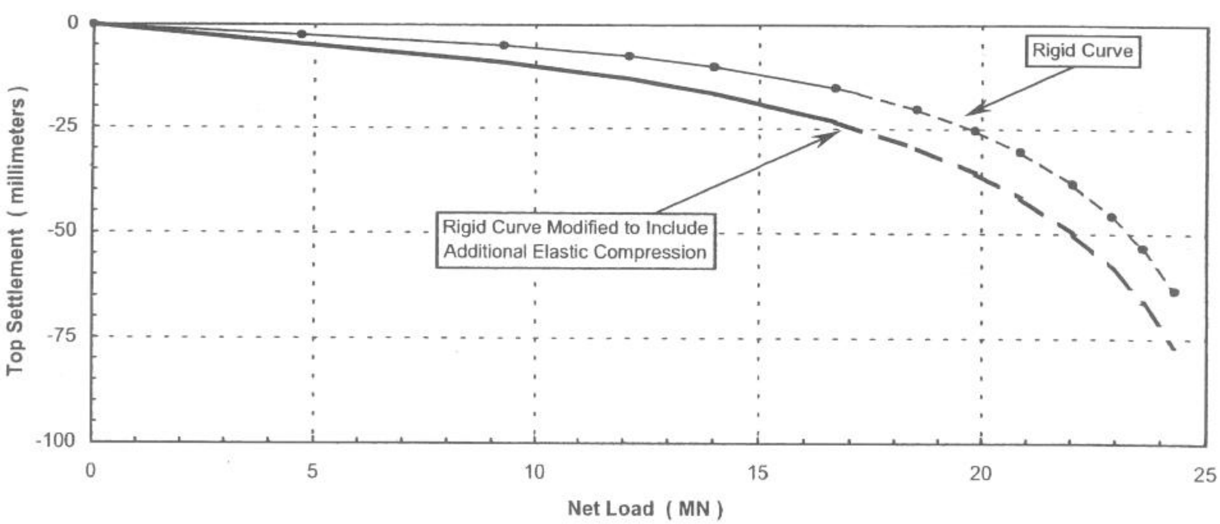
## Example Calcuation for the Additional Elastic Compression Correction for Single Level Test (SI Units)

**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) | $Q'_{\uparrow A}$ (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**



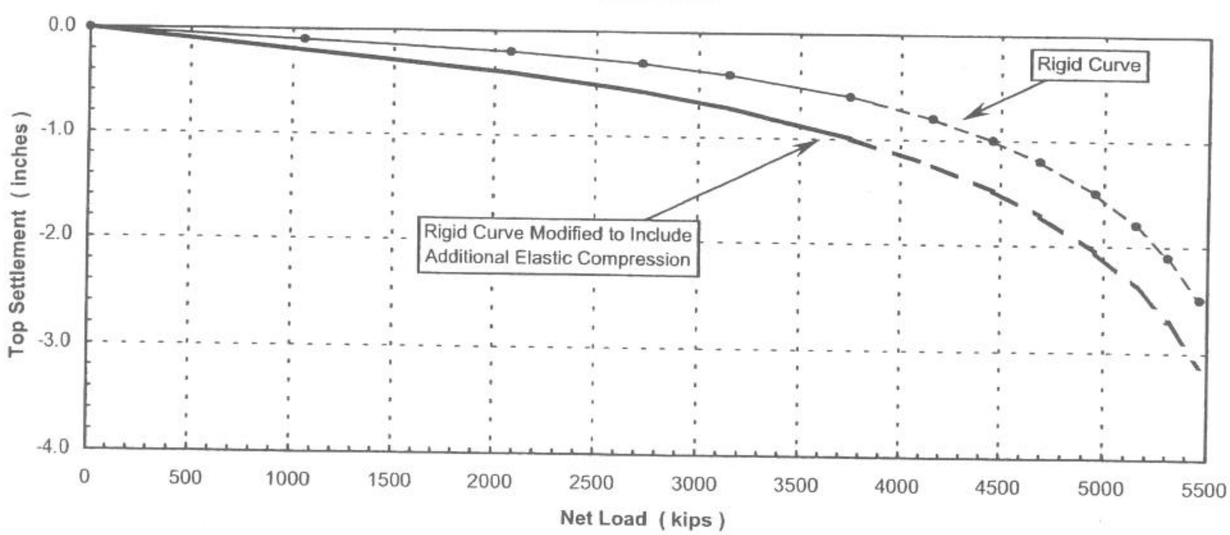
## Example Calcuation for the Additional Elastic Compression Correction for Multi Level Test (English Units)

**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)

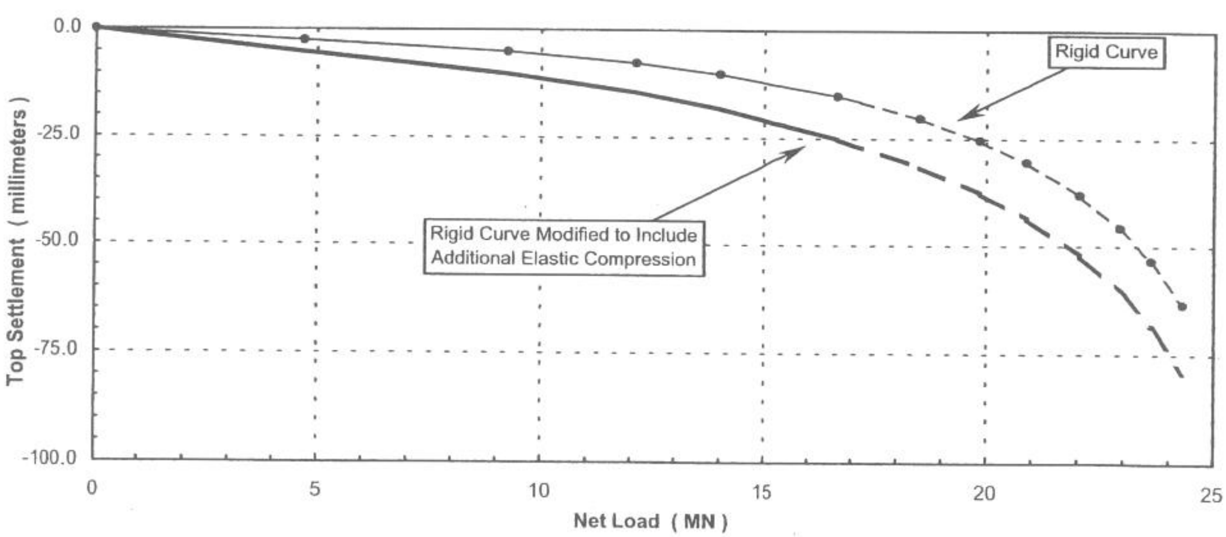
**Given:**

$C_1$ = 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 (April, 2000)

**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 D4719-94, 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 may 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.

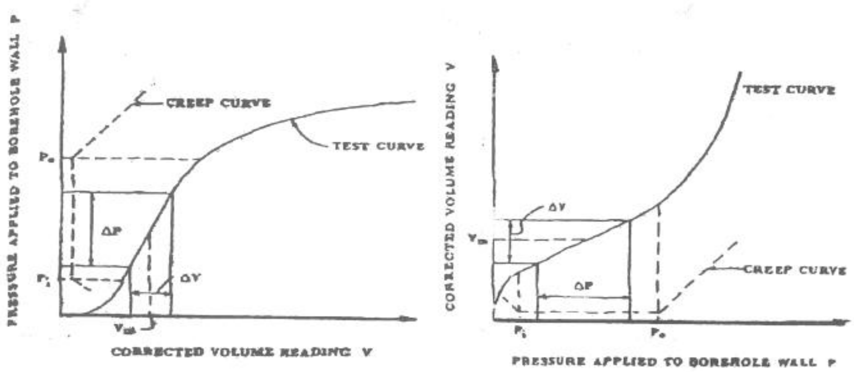



**FIG. 8 Pressuremeter Test Curves for Procedure A**

References


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

Stoll, M.U.W. (1961, Discussion, Proc. 5th 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. (1996), Basics of Foundation Design, BiTech Publishers Ltd., p.79.

# APPENDIX E

## SOIL BORING LOGS

# KANSAS DEPARTMENT OF TRANSPORTATION

| | | |
|---|---|---|
| RTE./CO. US-36/Republic Co | SOUNDING NO. CD 1-1 | SHEET 1 OF 2 |
| BRIDGE STA. 3-715.830 | PROJ.NO. 36-79 K-5043-01 | BRIDGE NO. 36-79-07.60(xxx) |
| SITE NAME US-36 over Republican River | | HOLE STA. 3-499.5, 11.9 Lt |
| GEOLOGIST N.Croxton | SCALE 1:100 (10mm=1m) | DATE 5/2/00 |
| DRILLER B.Bergman | RIG TYPE Mobile B-51 | TOP HOLE ELEV. 436.70 |
| GW ELEV. 434.80 (caved) | TOTAL DEPTH 16.92 | M/B ELEV. 430.75 |

| BIT TYPE | GEOLOGIC NAME | STRATIGRAPHIC COLUMN | DEPTH | ELEVATION | CLASSIFICATION OF MATERIALS DESCRIPTION AND REMARKS | UNCONFINED COMPRESSION | STANDARD PENETRATION TEST (SPT) N COUNT | STANDARD PENETRATION TEST (SPT) ELEVATION |
|---|---|---|---|---|---|---|---|---|
| | | | | | THE 436.70 | | | |
| 8" Hollow Stem Augers | Alluvium | | | 436 | Sand, silty, light brown, fine to medium grained, gravels and wood near base. | 118.5 | | 436.09 |
| | | | | 433 | | | 3 | 433.20 |
| | | | | 432 | | | 12 | 431.67 |
| | | | 5.95 | 431 | 430.75 | | | |
| NX Carbide | Graneros Shale Formation | | | 430 | Shale, dark gray, finely laminated | | 86 | 430.15 |
| | | 1 | | | 6.6 | 632.0 | | 430.02 |
| | | | | 429 | 16.3 | 1556.9 | | 429.12 |
| | | 2 | | 428 | 12.7 | 1220.8 | | 428.07 |
| | | | 9.90 | 427 | 16.0 / 426.80 | 1531.5 | | 427.10 |
| | | 3 | | 426 | Shale, dark to light gray, numerous thin, wavy, limey lenses, few fossils, bentonitic zones, weathered, broken zones and competent zones | | | |
| | | 4 | | | 4.4 | 422.1 | | 425.46 |
| | | | | 425 | 9.8 | 939.9 | | 424.74 |
| | | | | | 11.4 | 1095.3 | | 424.34 |
| | | 5 | 12.80 | 424 | 423.9 | | | |
| | | | | 423 | Sandstone, dk gray, fine grained, shaley, soft, interbedded shale seams, pyrite, peat bed below 419.9. | | | |
| | | 6 | | | 1.4 | 132.6 | | 422.46 |
| | | 7 | | | | | | |

# WSAS DEPARTMENT OF .RANSPORTATION

| RTE./CO. US-36/Republic Co | SOUNDING NO. CD 1-1 | SHEET 2 OF 2 |
|---|---|---|
| BRIDGE STA 3-715.830 | PROJ.NO. 36-79 K-5043-01 | BRIDGE NO. 36-79-07.60(xxx) |
| SITE NAME US-36 over Republican River | | HOLE STA 3-499.5, 11.9 Lt |

| BIT TYPE | GEOLOGIC NAME | STRATIGRAPHIC COLUMN | DEPTH | ELEVATION | CLASSIFICATION OF MATERIALS DESCRIPTION AND REMARKS | UNCONFINED COMPRESSION | STANDARD PENETRATION TEST (SPT) N COUNT | SPT ELEVATION |
|---|---|---|---|---|---|---|---|---|
| | Graneros Shale Formation | 7 | | 421 | SS .same, peat bed below 419.9. 3.4 | 328.6 | | 421.78 |
| | | 8 | | 420 | 1.5 | 147.3 | | 420.30 |
| | | | | | 419.78 | | | |
| | | | | 419 | | | | |

| Core | Depth | Elev | Cut | Rec | % | RQD |
|---|---|---|---|---|---|---|
| 1 | 6.55 | 430.15 | 0.55 | 0.47 | 86 | 22 |
| 2 | 7.10 | 429.60 | 1.53 | 1.54 | 101 | 58 |
| 3 | 8.63 | 428.07 | 1.52 | 1.43 | 94 | 38 |
| 4 | 10.15 | 426.55 | 1.44 | 0.81 | 56 | 48 |
| 5 | 11.59 | 425.11 | 1.12 | 1.56 | 139 | 100 |
| 6 | 12.71 | 423.99 | 1.53 | 0.73 | 48 | 19 |
| 7 | 14.24 | 422.46 | 1.16 | 1.40 | 1.21 | 61 |
| 8 | 15.40 | 421.30 | 1.52 | 1.10 | 72 | 61 |
| Total | 16.92 | 419.78 | 10.37 | 9.04 | 87 | |

**US-36 over Republican River**
**36-79 K-5043-02**
**Br. No. 36-79-07.60**

Core Drill Hole 1
Sta 3+580.1, 17.9 Rt.
T.H.E.
437.06

| | | | |
|---|---|---|---|
| | 437.060 | 0.00-1.07 | Silty clay, sandy, gray |
| | 435.990 | 1.07-1.52 | Gravel, fine to course |
| | 435.540 | 1.52-5.82 | Sand, medium to course |
| | 431.240 | 5.82-6.25 | Shale, very dark gray, hard |
| Core 1<br>6.21-7.12<br>Cut 0.87<br>Rec 0.84<br>RQD 68% | 430.810 | 0.00-0.87 | Shale, very dark gray, thinly laminated, clayey, hard |
| Core 2<br>7.12-8.66<br>Cut 1.54<br>Rec 1.48<br>RQD 80% | 429.940 | 0.00-0.91 | Shale, very dark gray |
| | 429.030 | 0.91-1.48 | Shale, very dark gray to gray, sandstone lenses with cross-bedding, fossil fragments, thin laminae, clayey. |
| | *S 10* | *7.78-7.93* | *Shale, very dark gray* |
| Core 3<br>8.66-10.18<br>Cut 1.52<br>Rec 1.48<br>RQD 56% | 428.400 | 0.00-0.80 | Shale, very dark gray, greenish, sandy, fossil zones, weathered |
| | 427.600 | 0.80-1.15 | Bentonite, blue gray, soft |
| | 427.250 | 1.15-1.52 | Shale, very dark gray, sandy seams, fossil zones |
| | *S 1* | *8.71-8.86* | *Shale, gray, sandy* |
| | *S 2* | *9.56-9.70* | *Bentonite, light gray* |
| Core 4<br>10.18-1170<br>Cut 1.52<br>Rec 1.40<br>RQD 95% | 426.880 | 0.00-0.05 | Sandstone, hard, gray, limey |
| | 426.830 | 0.05-1.40 | Shale, very dark gray, sandy |
| | *S 3* | *10.56-10.70* | *Shale, dark gray, sandy* |

**US-36 over Republican River**
**36-79 K-5043-02**
**Br. No. 36-79-07.60**

| | | | |
|---|---|---|---|
| Core 5<br>11.70-13.11<br>Cut 1.41<br>Rec 1.41<br>RQD 92% | 425.360<br>424.960 | 0.00-0.40<br>0.40-1.41 | Shale, sandy lenses, dark gray, firm, silty<br>Sandstone, gray, very shaley, cross-bedded |
| | *S 4*<br>*S 5* | *12.25-12.37*<br>*12.97-13.11* | *Sandstone, gray, shaley*<br>*Shale, gray, sandy* |
| Core 6<br>13.11-14.63<br>Cut 1.52<br>Rec 1.46<br>RQD 54% | 423.950<br>422.960 | 0.00-0.99<br>0.99-1.52 | Shale, dark gray, firm to soft, sandy zones<br>Sandstone, green-gray, poorly cemented, shaley, fine to medium grained, very weathered, crumbly |
| | *S 6* | *13.96-14.10* | *Shale, sandy, gray* |
| Core 7<br>15.85-17.38<br>Cut 1.52<br>Rec 1.43<br>RQD 30% | 422.430 | 0.00-1.52 | Shale, very sandy, thin bedded, broken, very weathered, firmer, more competent below 421.63, thin sand lenses, pyrite nodules |
| | *S 7* | *15.61-15.75* | *Shale, sandy, gray* |
| Core 8<br>16.15-17.68<br>Cut 1.53<br>Rec 0.63<br>RQD 75% | 420.910<br>419.760 | 0.00-0.43<br>0.43-1.53 | Shale, very dark gray, sand lenses, competent, pyrite nodules<br>Sandstone, dark gray, shaley, pyrite nodules, very weathered, significant wash |
| | *S 8* | *16.15-16.29* | *Shale, gray, sandy* |

**US-36 over Republican River**
**36-79 K-5043-02**
**Br. No. 36-79-07.60**

| | | | |
|---|---|---|---|
| Core 9<br>17.68-18.29<br>Cut 0.61<br>Rec 0.13<br>RQD 0% | 419.380 | 0.00-0.61 | Sandstone, shaley, poorly cemented, pyrite, weathered, significant wash |
| Core 10<br>18.29-19.32 | 418.77 | 0.00-0.70 | Sandstone, gray, fine gravel, shaley, poorly cemented, washed lower portion |
| Cut 1.03<br>Rec 0.69<br>RQD 38% | 418.07 | 0.70-1.03 | Shale, sandy zones, dark gray with brown seams, competent |
| | *S 9* | *19.19-19.32* | *Shale, gray, sandy* |

TD 19.32m
Bottom Hole Elev. 417.740

**Level Runs**

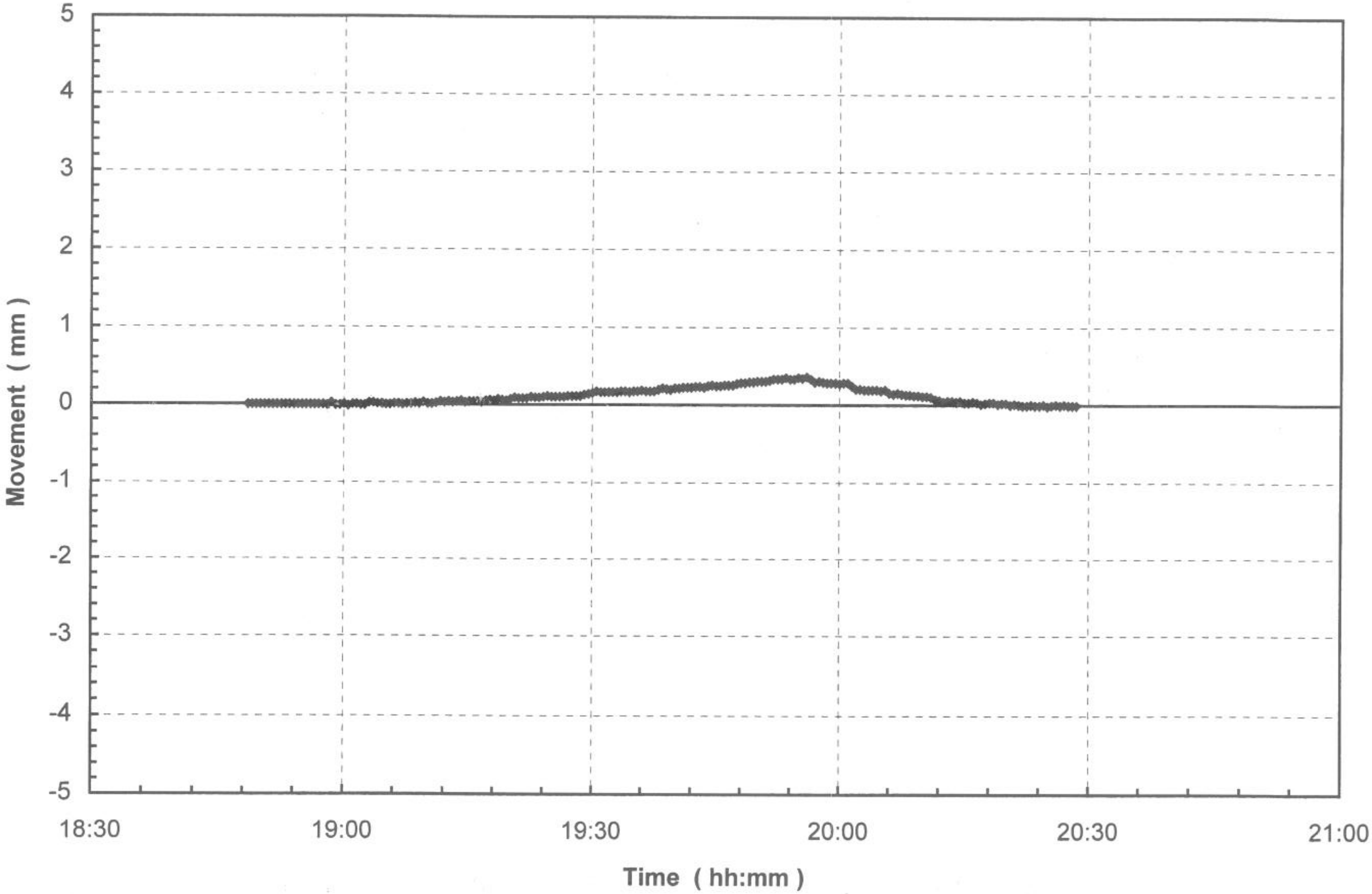
| | (+) | HI | (-) | Elev. | |
|---|---|---|---|---|---|
| TBM | 0.13 | 438.76 | | 438.630 | " " cut NE Corner Existing Pier 4 cross-member |
| CD3 | | | 1.70 | 437.060 | |

# APPENDIX F

## REFERENCE BEAM MONITORING

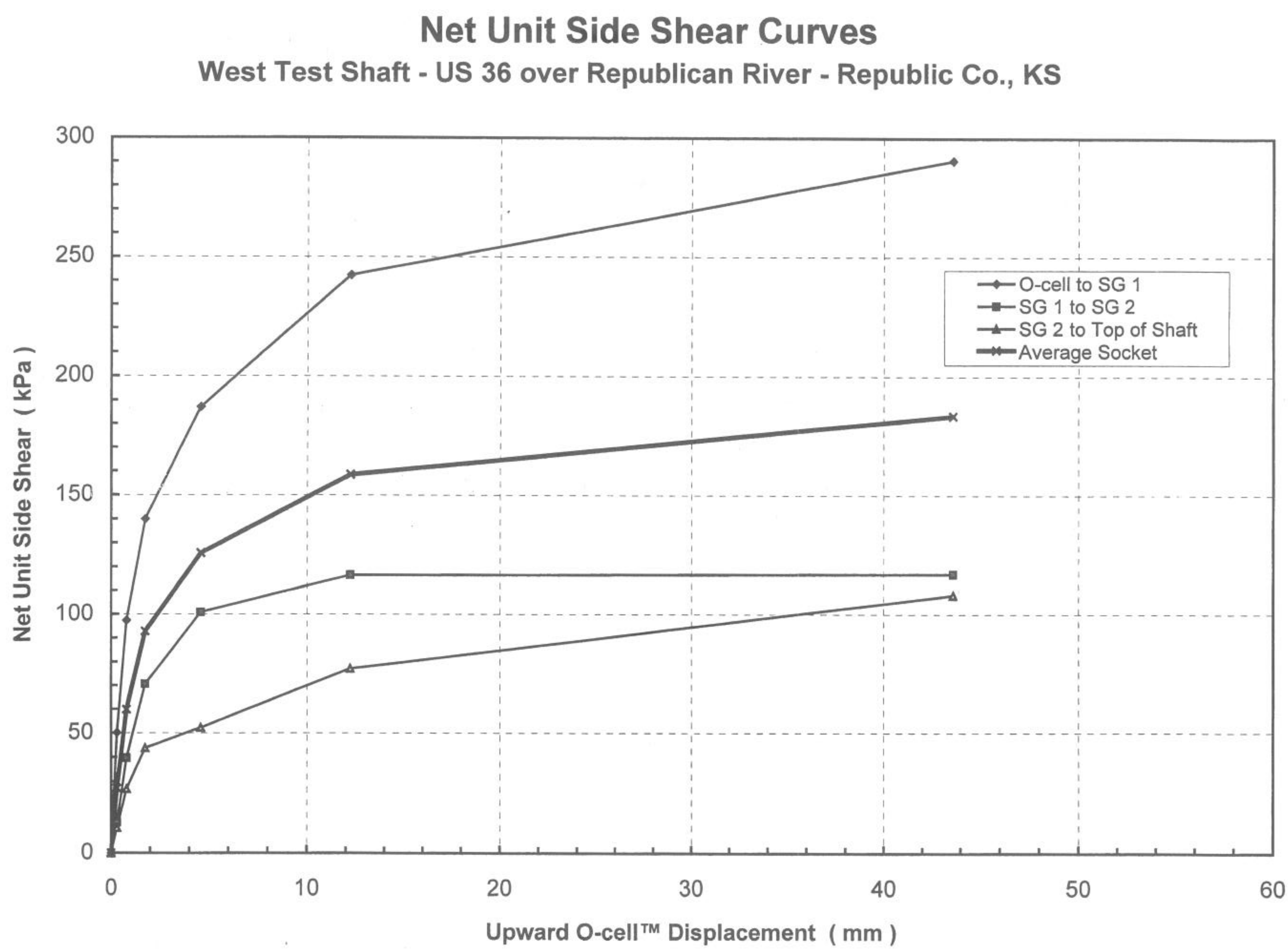
## Reference Beam Monitoring

### West Test Shaft - US 36 over Republican River - Republic Co., KS



# APPENDIX G

## NET UNIT SHEAR AND UNIT END BEARING CURVES



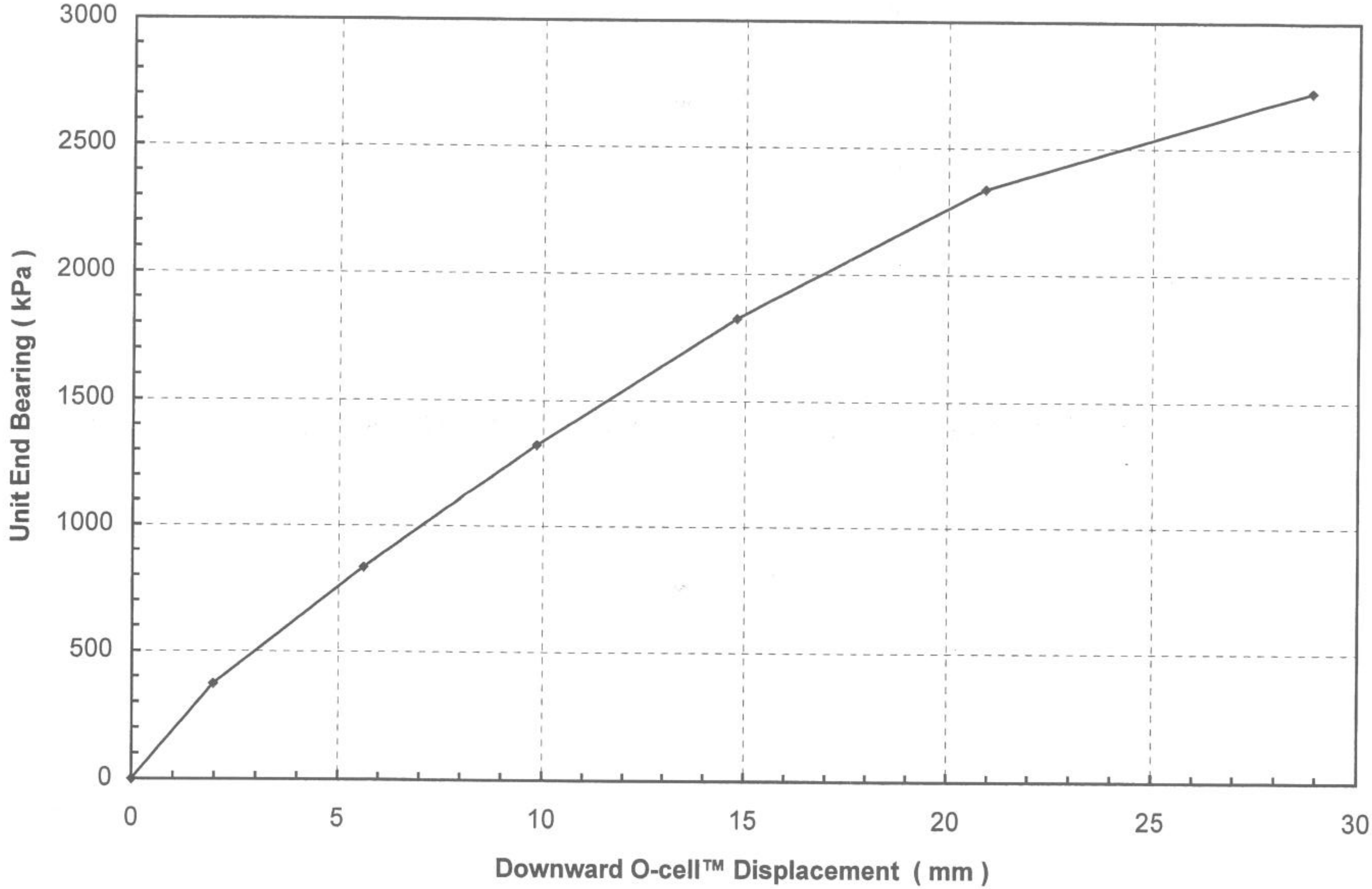





Appendix G - Figure 1

# Unit End Bearing Curve

## West Test Shaft - US 36 over Republican River - Republic Co., KS






Appendix G - Figure 2