REPORT ON DRILLED SHAFT LOAD TESTING (OSTERBERG METHOD)

Test Shaft #2 - I-235 / 28th Street Overpass
Des Moines, IA (LT-8756-2)

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

Attention: Mr. Mike Kemery

PROJECT NUMBER: LT-8756-2, August 13, 2002

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LOADTEST

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August 13, 2002

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

Attention: Mr. Mike Kemery

Load Test Report: Test Shaft #2 - I-235 / 28th Street Overpass
Location: Des Moines, IA (LT-8756-2)

Dear Mr. Mike Kemery,

The enclosed report contains the data and analysis summary for the O-cell™ test performed on Test Shaft #2 - I-235 / 28th Street Overpass, on August 7, 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,

William G. Ryan
Midwest Regional Manager / LOADTEST, Inc.

EXECUTIVE SUMMARY

On August 7, 2002, we tested a 1219-mm (48-inch) production shaft constructed by Longfellow Drilling, Inc. Mr. M. D. Ahrens and Mr. J. A. Graman of LOADTEST, Inc. carried out the test. Longfellow Drilling, Inc. excavated the 20.42-m (67.0-ft) deep shaft socketed in shale under polymer slurry on August 2, 2002. Sub-surface conditions at the test shaft location consist primarily of stiff to firm silty glacial clay underlain by clay shale bedrock. Representatives of IDOT and FHWA observed construction and testing of the shaft.

The maximum bi-directional load applied to the shaft was 6.57 MN (1,476 kips). At the maximum load, the displacements above and below the O-cell were 14.83 mm (0.584 inches) and 4.68 mm (0.184 inches), respectively. Average unit shear data calculated from strain gages included a maximum calculated net unit side shear of 339 kPa (7.1 ksf), occurring between the strain gage levels 1 and 2. The maximum calculated unit end bearing is 5462 kPa (114.1 ksf). These unit values occurred at the above noted displacements.

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 7.3 MN (1,643 kips), the adjusted test data indicate this shaft would settle approximately 6.4 mm (0.25 inches) of which 4.1 mm (0.16 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.

TABLE OF CONTENTS

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 stiff to firm silty glacial clay underlain by clay shale bedrock. 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 Iowa DOT and FHWA.

Test Shaft Construction: Longfellow Drilling, Inc. excavated the production test shaft and performed the final cleanout and concreting on August 2, 2002. We understand that the 1,219-mm (48-inch) test shaft was constructed to a tip elevation of 251.30 m (824.5 ft), under polymer slurry. The shaft was started with a 1372-mm (54-inch) O.D. surface casing. An auger and a core barrel were used for drilling the shaft. The sides of the shaft were cleaned with a sweep bucket and then grooved with a modified auger. The bottom of the shaft was then cleaned with a bucket and airlifted. After cleaning the base, the reinforcing cage with attached O-cell™ assembly was inserted into the excavation and suspended approximately 460 mm (18 inches) above the tip of shaft. Concrete was then delivered by pump through a 125-mm (5-inch) O.D. pipe into the base of the shaft until the cage began to float. The cage was then allowed to settle until the base of the O-cell™ was 0.22 meters (0.7 feet) above the tip of shaft. The pumpline was then raised above the O-cell™ and concreting resumed until the concrete reached an elevation of +271.28 meters (+890.0 feet). The contractor removed the 1372-mm (54-inch) O.D. casing immediately after concrete placement. No unusual problems occurred during construction of the shaft. Representatives of the IDOT and FHWA observed construction of the shaft.

OSTERBERG CELL TESTING

Shaft Instrumentation: Test shaft instrumentation and assembly was carried out under the direction of Mr. William G. Ryan of LOADTEST, Inc. on July 31, 2002. The loading assembly consisted of a 670-mm O-cell™, located 0.22 meters (0.7 feet) above the tip of shaft. The Osterberg cell was calibrated to 13.7 MN (3,080 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.

Standard O-cell™ testing instrumentation included three Linear Vibrating Wire Displacement Transducers (LVWDTs) – (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. Five levels of two sister bar vibrating wire strain gages (Geokon Model 4911 Series) were installed diametrically opposed in the shaft above the Osterberg cell assembly. Details concerning the strain gage placement appear in Table B and Figure A. The strain gages were positioned as directed by the FHWA.

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 (described under Shaft Instrumentation) monitored by Linear Voltage Displacement Transducers (LVDTs) (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 a 7.6-meter (25-foot) steel wide flange section supported on large wooden spools. The supports were located approximately three shaft diameters from the center of the test shaft. An automated digital survey level (Leica NA 3003) was used to monitor the reference beam for movement during testing from a distance of approximately 12 meters (40 feet) (Appendix F). The maximum downward movement measured was -0.63 mm (0.025 inches). The top of shaft movements have been corrected for movement of the reference system (Appendix A, Page 1).

Both a Bourdon pressure gauge 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-10), 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 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 for placement in 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 8.27 MPa (1,200 psi) to the O-cell™.

The Osterberg cell load test was conducted as follows: We pressurized the 670-mm (26-inch) diameter O-cell™, with its base located 0.22 meters (0.7 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 eight loading increments to 27.58 MPa (4,000 psi) resulting in a bi-directional gross O-cell™ load of 6.57 MN (1,476 kips). The loading was halted after load interval 1L-8 because the side shear was approaching ultimate capacity. The O-cell™ was then depressurized in four decrements. The O-cell™ was then repressurized in three loading increments to a bi-directional gross O-cell™ load of 4.94 MN (1,110 kips) at 2L-3. The O-cell™ was then 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.

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 curve. For this test we calculated a buoyant weight of shaft of 0.58 MN (131 kips) above the O-cell™.

Side Shear Resistance: The maximum upward applied *net load* to the upper side shear was 5.98 MN (1,345 kips) which occurred at load interval 1L-8 (Appendix A, Page 1, Figure 1). At this loading, the upward movement of the O-cell™ top was 14.83 mm (0.584 inches). Net unit shear curves are presented in Appendix G.

In order to assess the side shear resistance of the test shaft, loads are calculated based on the strain gage data (Appendix A, Pages 4 and 5) 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 26.20 MPa (3,800 psi) on the day of the test. This, combined with the area of reinforcing steel and nominal shaft diameter, provided an average shaft stiffness (AE) of 39,000 MN (8,767,986 kips) in the 1372 mm (54-inch) diameter temporarily cased shaft section and 31,500 MN (7,081,835 kips) in the nominal 1219 mm (48-inch) diameter shaft section above the O-cell™. 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-8 follow in Table A:

TABLE A: Average Net Unit Side Shear Values for 1L-8

Load Transfer Zone	Load Direction	Net Unit Side Shear *
Top of Concrete to Strain Gage Level 5	↑	16 kPa (0.3 ksf)
Strain Gage Level 5 to Strain Gage Level 4	↑	18 kPa (0.4 ksf)
Strain Gage Level 4 to Strain Gage Level 3	↑	24 kPa (0.5 ksf)
Strain Gage Level 3 to Strain Gage Level 2	↑	69 kPa (1.4 ksf)
Strain Gage Level 2 to Strain Gage Level 1	↑	335 kPa (7.0 ksf)
Strain Gage Level 1 to O-cell™	↑	243 kPa (5.1 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 above the O-cell™ assembly may not be ultimate values. See Appendix G for net unit shear vs. upward O-cell™ displacement plots.

Combined End Bearing and Lower Side Shear Resistance: The maximum O-cell™ load applied to the combined end bearing and lower side shear was 6.57 MN (1,476 kips) which occurred at load interval 1L-8 (Appendix A, Page 3, Figure 1). At this loading, the average downward movement of the O-cell™ base was 4.68 mm (0.184 inches). The load taken in shear by the 0.22 meters (0.7 feet) shaft section below the O-cell™ is calculated to be 0.19 MN (43 kips) assuming an estimated unit side shear value of 225 kPa (4.7 ksf) and a nominal 1,219-mm (48-inch) diameter shaft. The applied load to end bearing is then 6.38 MN (1,434 kips) and the unit end bearing at the base of the shaft is calculated to be 5462 kPa (114.1 ksf) at the above noted displacement. A unit end bearing curve is presented in Appendix G.

Creep Limit: See Appendix D for our O-cell™ method for determining creep limit. The base creep data (Appendix A, Page 3) indicate that no apparent creep limit was reached at a maximum movement of 4.7 mm (0.18 inches) (Figure 4). The side shear creep data (Appendix A, Page 3) indicate that a creep limit of 4.4 MN (989 kips) was reached at a movement of 5.0 mm (0.20 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 10.8 MN (2,438 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 14.8 mm (0.58 inches) by extrapolating the base 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 12.5 MN (2,821 kips). For a top loading of 7.3 MN (1,643 kips), the adjusted test data indicate this shaft would settle approximately 6.4 mm (0.25 inches) of which 4.1 mm (0.16 inches) is estimated elastic compression. For a top loading of 16.9 MN (3,798 kips) the adjusted test data indicate this shaft would settle approximately 23.5 mm (0.92 inches) of which 9.5 mm (0.37 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 shaft 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 0.93 mm (0.037 inches) at 1L-8 (Appendix A, Page 1). Using an average shaft stiffness of 32,300 MN (7,280,000 kips) and the load distribution in Figure 3 at 1L-8, we calculated an elastic compression of 0.90 mm (0.035 inches) over the length of the compression telltales. We believe this excellent 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 calibration.

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.

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.

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

Michael D. Ahrens, P.E.
Geotechnical Engineer / LOADTEST, Inc.

Reviewed by

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

Denton A. Kort, P. E.
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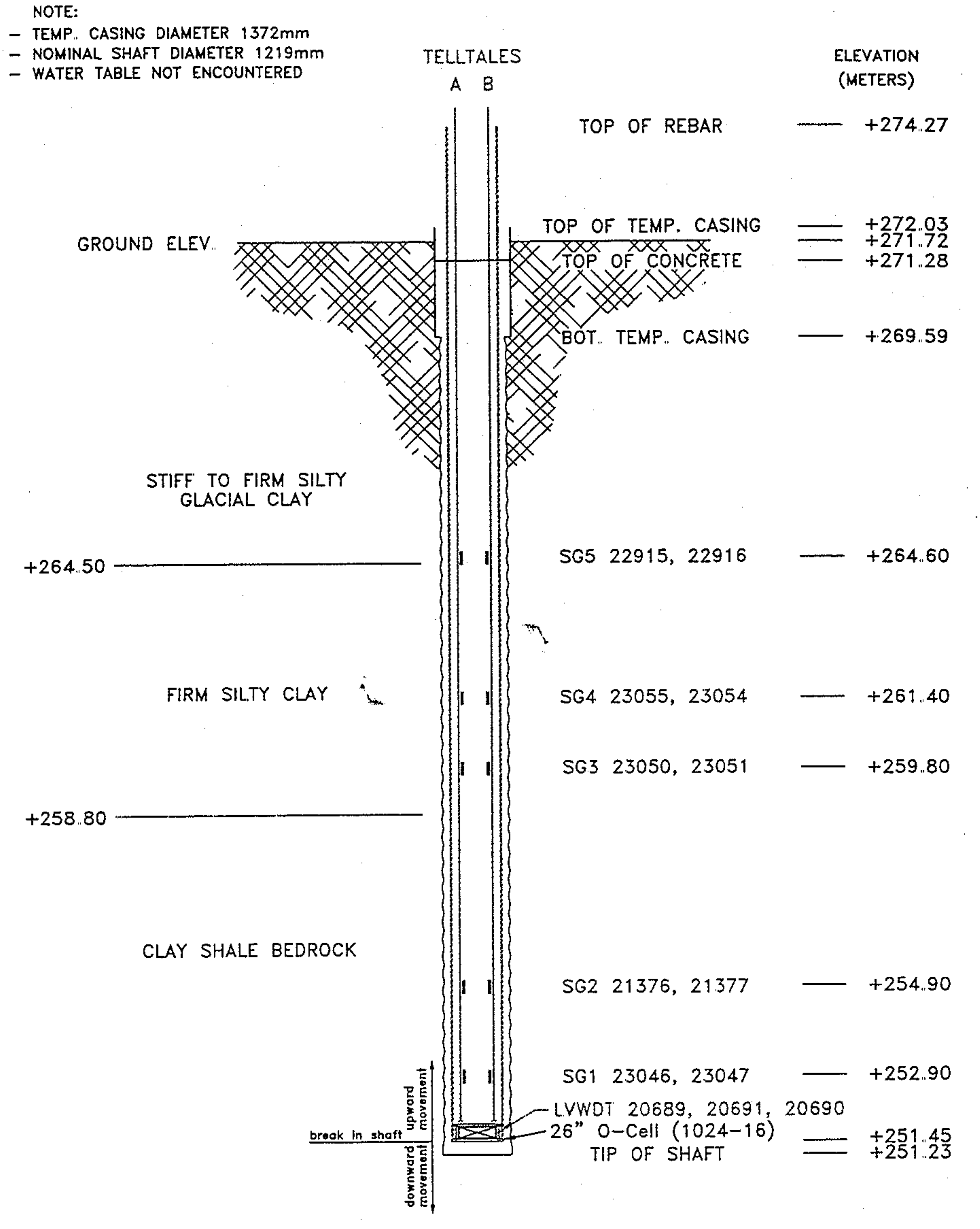
William G. Ryan
Midwest Regional Manager / LOADTEST, Inc.

TABLE B:
SUMMARY OF DIMENSIONS, ELEVATIONS & SHAFT PROPERTIES

Shaft:			
Nominal shaft diameter (EL +271 28 m to +269 59 m)	=	1372 mm	54 in
Nominal shaft diameter (EL +269 59 m to +251 45 m)	=	1219 mm	48 in
O-cell™: 1024-16	=	670 mm	26 in
Bouyant weight of pile above base of O-cell™	=	0 58 MN	131 kips
Estimated shaft stiffness AE (EL +271 28 m to +269.59 m)	=	39,000 MN	8,800,000 kips
Estimated shaft stiffness, AE (EL +269 59 m to +251 45 m)	=	31 500 MN	7,100,000 kips
Elevation of ground surface	=	+271.72 m	+891 5 ft
Elevation of top of shaft concrete	=	+271 28 m	+890 0 ft
Elevation of base of O-cell™ (The break between upward and downward movement)	=	+251 45 m	+825 0 ft
Elevation of shaft tip	=	+251.23 m	+824.2 ft
Elevation of water table	=	Not Encountered	
Casings:			
Elevation of top of inner temporary casing (1372 mm O.D.)	=	+272 03 m	+892 5 ft
Elevation of bottom of inner temporary casing (1372 mm O.D)	=	+269.59 m	+884 5 ft
Compression Sections:			
Elevation of top of telltale used for shaft compression	=	+271 28 m	+890.0 ft
Elevation of bottom of telltale used for shaft compression	=	+251.80 m	+826 1 ft
Strain Gages:			
Elevation of strain gage Level 5	=	+264.60 m	+868.1 ft
Elevation of strain gage Level 4	=	+261.40 m	+857.6 ft
Elevation of strain gage Level 3	=	+259.80 m	+852.4 ft
Elevation of strain gage Level 2	=	+254.90 m	+836.3 ft
Elevation of strain gage Level 1	=	+252.90 m	+829 7 ft
Miscellaneous:			
Top plate diameter (50 mm thickness)	=	959 mm	37 8 in
Bottom plate diameter (50 mm thickness)	=	1035 mm	40 8 in
ReBar size (18 No)	=	M 36	# 11
Spiral size (305 mm spacing)	=	M 13	# 4
ReBar cage diameter	=	1067 mm	42 in
Unconfined compressive concrete strength	=	26.2 MPa	3800 psi
O-cell™ LVWDTs @ 0°, 180° and 270° with radius	=	502 mm	19 8 in



LOADTEST	2631-D NW 41st St. Gainesville, FL 32606 Phone 800-368-1138 FAX (352) 378-3934	SCHEMATIC SECTION OF TEST SHAFT #2	LT-8756-2 I-235/28th St. Overpass Des Moines, Iowa FIGURE A

Osterberg Cell Load-Movement Curves

Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA

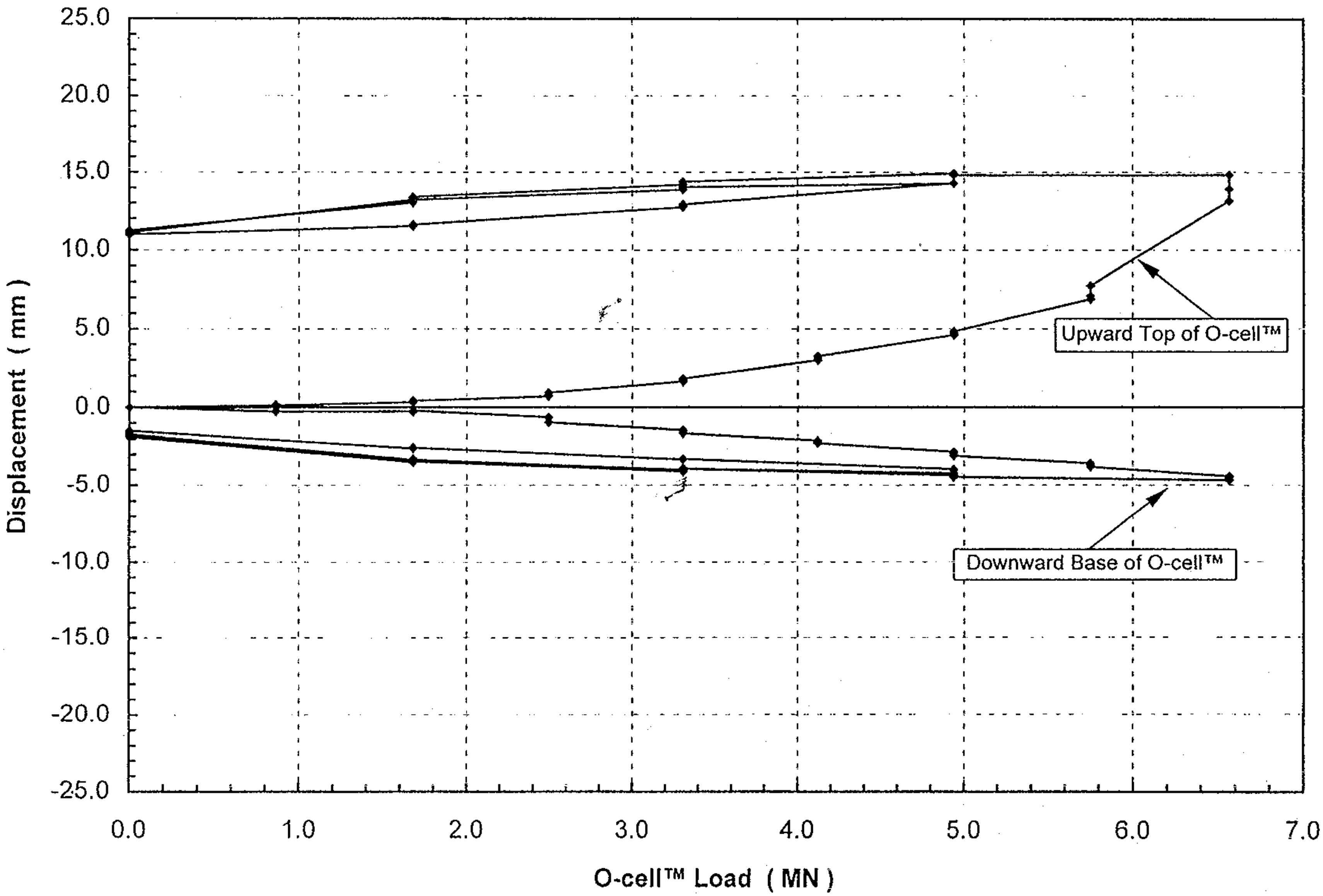


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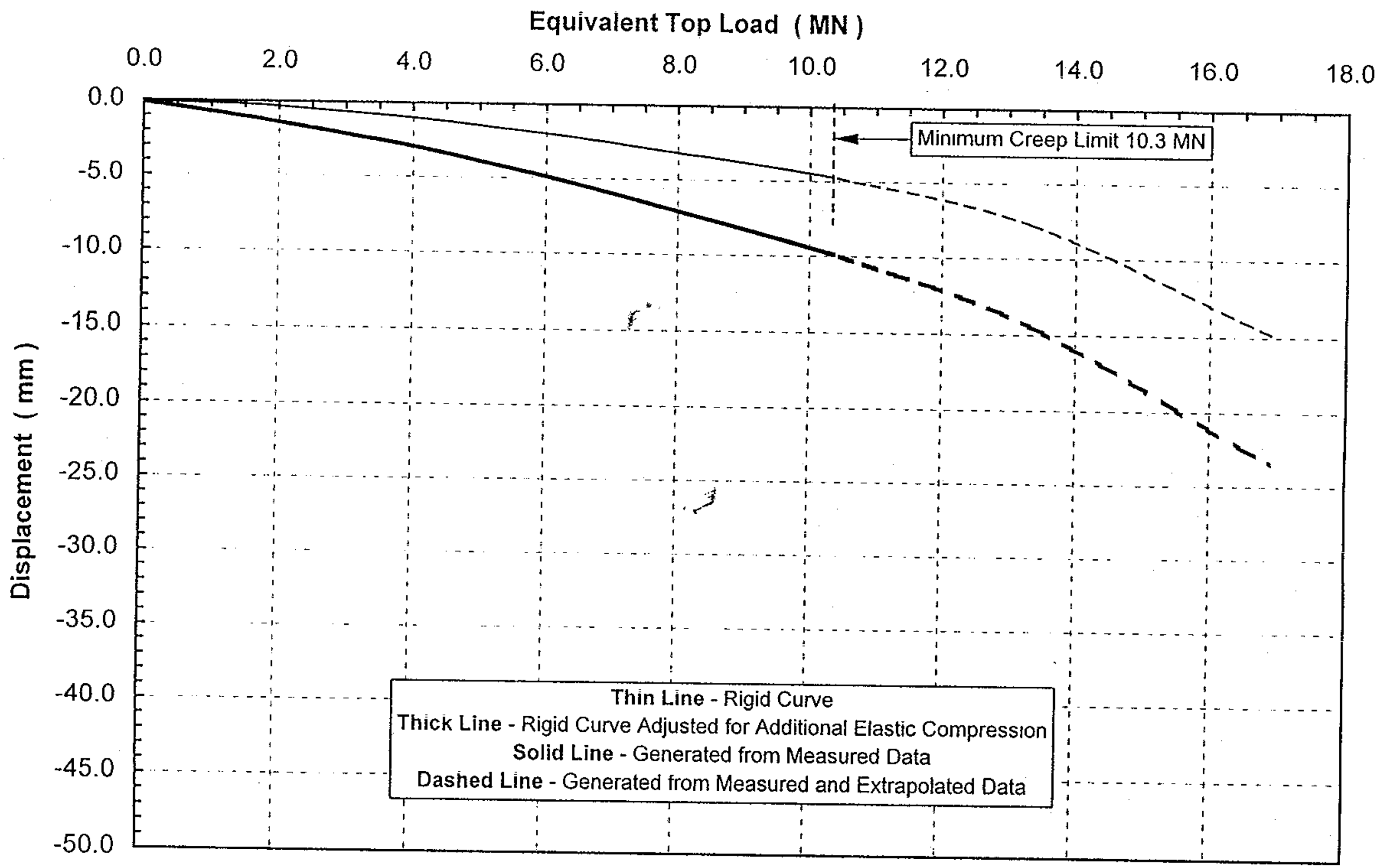
Figure 1 of 5

Equivalent Top Load Load-Movement Curve

Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA



Strain Gage Load Distribution Curves

Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA

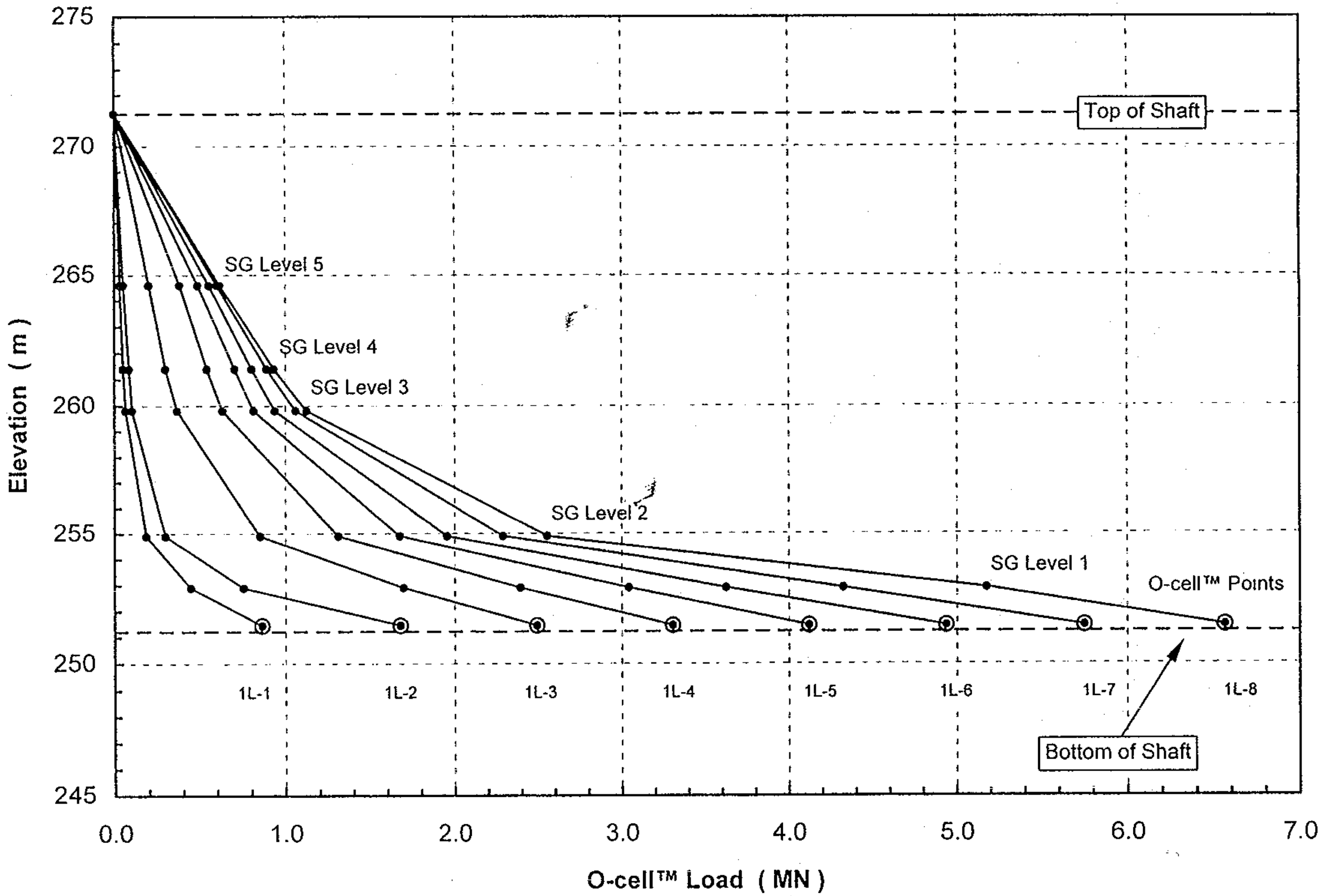


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Figure 3 of 5

Combined End Bearing and Lower Side Shear Creep Limit

Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA

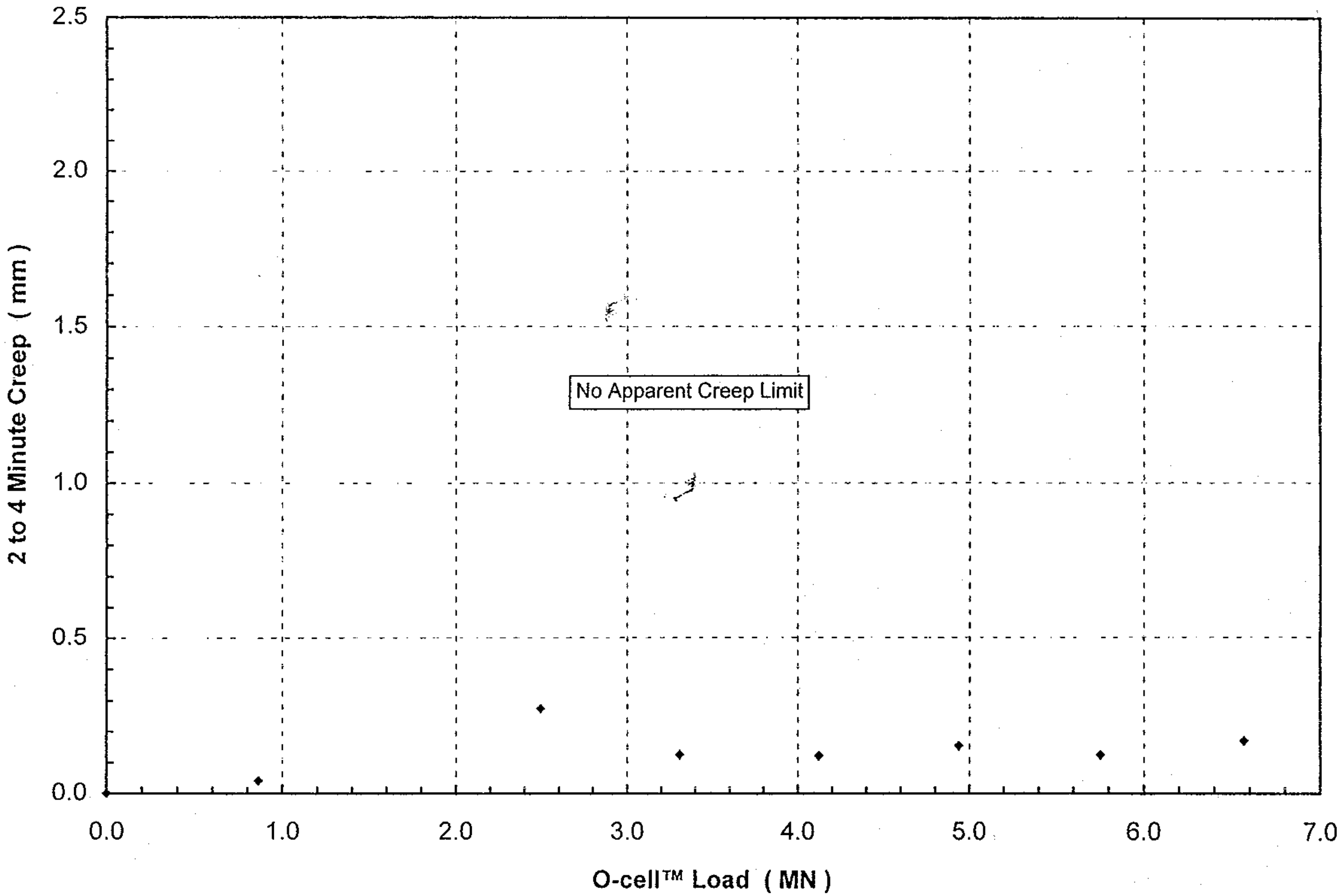

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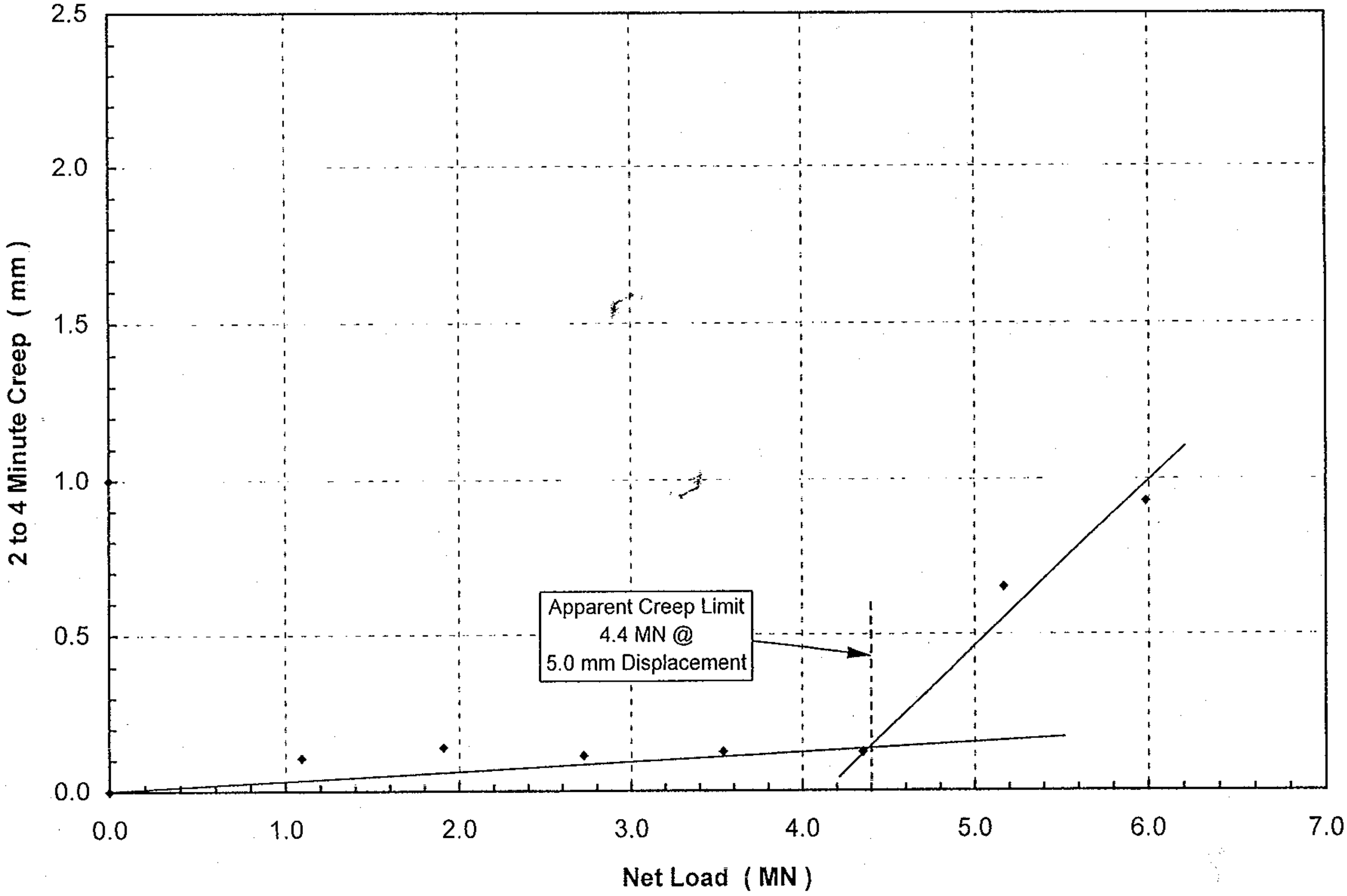
Figure 4 of 5

Side Shear Creep Limit

Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA



APPENDIX A

FIELD DATA & DATA REDUCTION

Upward Top of Shaft Movement and Shaft Compression
Test Shaft #2 - I-235 / 28th Street 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	-	10:36:00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1 L - 1	1	10:56:30	500	3.45	0.86	-0.23	0.29	0.27	0.05	0.05	0.09	0.07
1 L - 1	2	10:57:30	500	3.45	0.86	-0.20	0.29	0.33	0.10	0.05	0.08	0.06
1 L - 1	4	10:59:30	500	3.45	0.86	-0.21	0.26	0.27	0.06	0.05	0.08	0.06
1 L - 2	1	11:01:00	1,000	6.89	1.68	-0.18	0.37	0.40	0.20	0.09	0.13	0.11
1 L - 2	2	11:02:00	1,000	6.89	1.68	-0.20	0.39	0.40	0.20	0.09	0.13	0.11
1 L - 2	4	11:04:00	1,000	6.89	1.68	-0.14	0.42	0.48	0.31	0.08	0.13	0.10
1 L - 3	1	11:05:30	1,500	10.34	2.49	-0.13	0.58	0.61	0.47	0.17	0.26	0.21
1 L - 3	2	11:06:30	1,500	10.34	2.49	-0.13	0.66	0.66	0.53	0.19	0.30	0.25
1 L - 3	4	11:08:30	1,500	10.34	2.49	-0.17	0.76	0.82	0.62	0.24	0.35	0.29
1 L - 4	1	11:10:00	2,000	13.79	3.31	-0.16	1.31	1.34	1.16	0.39	0.52	0.45
1 L - 4	2	11:11:00	2,000	13.79	3.31	-0.20	1.39	1.47	1.23	0.39	0.53	0.46
1 L - 4	4	11:13:00	2,000	13.79	3.31	-0.20	1.50	1.58	1.33	0.41	0.54	0.47
1 L - 5	1	11:17:00	2,500	17.24	4.12	-0.08	2.39	2.52	2.37	0.52	0.69	0.61
1 L - 5	2	11:18:00	2,500	17.24	4.12	-0.07	2.49	2.62	2.48	0.51	0.70	0.61
1 L - 5	4	11:20:00	2,500	17.24	4.12	-0.09	2.62	2.78	2.61	0.51	0.69	0.60
1 L - 6	1	11:23:00	3,000	20.68	4.94	-0.12	3.88	4.05	3.85	0.61	0.83	0.72
1 L - 6	2	11:24:00	3,000	20.68	4.94	-0.13	4.04	4.18	3.98	0.61	0.83	0.72
1 L - 6	4	11:26:00	3,000	20.68	4.94	-0.17	4.20	4.37	4.12	0.60	0.82	0.71
1 L - 7	1	11:28:00	3,500	24.13	5.75	-0.09	6.06	6.27	6.08	0.68	0.95	0.82
1 L - 7	2	11:29:00	3,500	24.13	5.75	-0.14	6.32	6.53	6.29	0.68	0.93	0.81
1 L - 7	4	11:31:00	3,500	24.13	5.75	-0.08	6.90	7.11	6.93	0.68	0.95	0.82
1 L - 8	1	11:33:30	4,000	27.58	6.57	-0.02	12.13	12.27	12.18	0.82	1.09	0.95
1 L - 8	2	11:34:30	4,000	27.58	6.57	-0.02	12.91	13.05	12.96	0.80	1.07	0.94
1 L - 8	4	11:36:30	4,000	27.58	6.57	-0.12	13.94	14.10	13.89	0.80	1.06	0.93
1 U - 1	1	11:38:00	3,000	20.68	4.94	-0.12	14.04	14.12	13.97	0.70	0.99	0.84
1 U - 1	2	11:39:00	3,000	20.68	4.94	-0.10	14.04	14.20	14.02	0.70	0.98	0.84
1 U - 1	4	11:41:00	3,000	20.68	4.94	-0.09	14.09	14.25	14.08	0.70	0.97	0.83
1 U - 2	1	11:42:30	2,000	13.79	3.31	-0.17	13.81	13.96	13.71	0.54	0.81	0.68
1 U - 2	2	11:43:30	2,000	13.79	3.31	-0.19	13.78	13.96	13.68	0.53	0.80	0.67
1 U - 2	4	11:45:30	2,000	13.79	3.31	-0.27	13.70	13.89	13.52	0.53	0.80	0.67
1 U - 3	1	11:47:00	1,000	6.89	1.68	-0.29	13.15	13.26	12.91	0.34	0.59	0.46
1 U - 3	2	11:48:00	1,000	6.89	1.68	-0.32	13.12	13.29	12.88	0.33	0.58	0.46
1 U - 3	4	11:50:00	1,000	6.89	1.68	-0.42	13.10	13.26	12.75	0.34	0.57	0.45
1 U - 4	1	11:52:00	0	0.00	0.00	-0.47	11.36	11.51	10.97	0.05	0.22	0.13
1 U - 4	2	11:53:00	0	0.00	0.00	-0.49	11.28	11.38	10.84	0.05	0.20	0.12
1 U - 4	4	11:55:00	0	0.00	0.00	-0.43	11.23	11.30	10.84	0.05	0.20	0.12
2 L - 0	1	11:56:00	0	0.00	0.00	-0.41	11.21	11.30	10.85	0.04	0.20	0.12
2 L - 1	1	11:58:00	1,000	6.89	1.68	-0.38	11.52	11.64	11.20	0.21	0.40	0.31
2 L - 1	2	11:59:00	1,000	6.89	1.68	-0.35	11.57	11.67	11.27	0.21	0.40	0.31
2 L - 1	4	12:01:00	1,000	6.89	1.68	-0.35	11.57	11.70	11.28	0.21	0.41	0.31
2 L - 2	1	12:03:00	2,000	13.79	3.31	-0.37	12.49	12.61	12.18	0.43	0.66	0.55
2 L - 2	2	12:04:00	2,000	13.79	3.31	-0.38	12.57	12.69	12.25	0.43	0.67	0.55
2 L - 2	4	12:06:00	2,000	13.79	3.31	-0.35	12.65	12.79	12.37	0.44	0.67	0.55
2 L - 3	1	12:08:00	3,000	20.68	4.94	-0.37	13.80	13.96	13.52	0.65	0.90	0.78
2 L - 3	2	12:09:00	3,000	20.68	4.94	-0.40	13.83	14.01	13.52	0.64	0.89	0.77
2 L - 3	4	12:11:00	3,000	20.68	4.94	-0.46	13.86	14.07	13.50	0.64	0.89	0.77
2 U - 1	1	12:12:30	2,000	13.79	3.31	-0.45	13.72	13.91	13.37	0.53	0.80	0.67
2 U - 1	2	12:13:30	2,000	13.79	3.31	-0.40	13.64	13.78	13.31	0.53	0.80	0.67
2 U - 1	4	12:15:30	2,000	13.79	3.31	-0.42	13.57	13.65	13.19	0.52	0.81	0.67
2 U - 2	1	12:17:00	1,000	6.89	1.68	-0.45	13.12	13.20	12.72	0.33	0.59	0.46
2 U - 2	2	12:18:00	1,000	6.89	1.68	-0.54	13.09	13.18	12.60	0.32	0.59	0.45
2 U - 2	4	12:20:00	1,000	6.89	1.68	-0.56	13.07	13.15	12.55	0.32	0.59	0.46
2 U - 3	1	12:21:30	0	0.00	0.00	-0.62	11.67	11.77	11.10	0.04	0.23	0.14
2 U - 3	2	12:22:30	0	0.00	0.00	-0.60	11.60	11.64	11.01	0.04	0.22	0.13
2 U - 3	4	12:24:30	0	0.00	0.00	-0.63	11.57	11.74	11.02	0.03	0.22	0.13
2 U - 3	8	12:28:30	0	0.00	0.00	-0.50	11.49	11.53	11.01	0.03	0.20	0.12

* Positive values indicate upward reference beam movement

O-cell™ Expansion
Test Shaft #2 - I-235 / 28th Street 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 20689 (mm)	LVWDT 20691 (mm)	LVWDT 20690 * (mm)	Average (mm)
1 L - 0	-	10:36:00	0.00	0.00	0.00	0.00	0.00	0.00
1 L - 1	1	10:56:30	3.45	0.86	0.47	0.33	0.81	0.40
1 L - 1	2	10:57:30	3.45	0.86	0.48	0.34	0.84	0.41
1 L - 1	4	10:59:30	3.45	0.86	0.46	0.35	0.85	0.40
1 L - 2	1	11:01:00	6.89	1.68	0.64	0.51	1.22	0.57
1 L - 2	2	11:02:00	6.89	1.68	0.67	0.53	1.25	0.60
1 L - 2	4	11:04:00	6.89	1.68	0.70	0.55	1.28	0.63
1 L - 3	1	11:05:30	10.34	2.49	1.42	1.21	2.16	1.32
1 L - 3	2	11:06:30	10.34	2.49	1.50	1.40	2.45	1.45
1 L - 3	4	11:08:30	10.34	2.49	1.97	1.75	2.87	1.86
1 L - 4	1	11:10:00	13.79	3.31	3.18	2.92	4.31	3.05
1 L - 4	2	11:11:00	13.79	3.31	3.33	3.09	4.50	3.21
1 L - 4	4	11:13:00	13.79	3.31	3.58	3.31	4.76	3.45
1 L - 5	1	11:17:00	17.24	4.12	5.24	4.91	6.61	5.08
1 L - 5	2	11:18:00	17.24	4.12	5.44	5.06	6.81	5.25
1 L - 5	4	11:20:00	17.24	4.12	5.67	5.32	7.08	5.49
1 L - 6	1	11:23:00	20.68	4.94	7.65	7.18	9.26	7.42
1 L - 6	2	11:24:00	20.68	4.94	7.88	7.42	9.52	7.65
1 L - 6	4	11:26:00	20.68	4.94	8.18	7.67	9.83	7.93
1 L - 7	1	11:28:00	24.13	5.75	10.76	10.17	12.59	10.47
1 L - 7	2	11:29:00	24.13	5.75	11.09	10.49	12.93	10.79
1 L - 7	4	11:31:00	24.13	5.75	11.85	11.27	13.70	11.56
1 L - 8	1	11:33:30	27.58	6.57	17.92	17.18	19.93	17.55
1 L - 8	2	11:34:30	27.58	6.57	18.82	18.01	20.82	18.41
1 L - 8	4	11:36:30	27.58	6.57	19.93	19.08	21.92	19.51
1 U - 1	1	11:38:00	20.68	4.94	19.70	18.86	21.71	19.28
1 U - 1	2	11:39:00	20.68	4.94	19.69	18.86	21.71	19.28
1 U - 1	4	11:41:00	20.68	4.94	19.68	18.86	21.70	19.27
1 U - 2	1	11:42:30	13.79	3.31	18.75	17.93	20.68	18.34
1 U - 2	2	11:43:30	13.79	3.31	18.64	17.84	20.57	18.24
1 U - 2	4	11:45:30	13.79	3.31	18.60	17.82	20.53	18.21
1 U - 3	1	11:47:00	6.89	1.68	17.10	16.35	18.86	16.72
1 U - 3	2	11:48:00	6.89	1.68	16.99	16.26	18.75	16.62
1 U - 3	4	11:50:00	6.89	1.68	16.91	16.18	18.67	16.55
1 U - 4	1	11:52:00	0.00	0.00	13.16	12.45	14.34	12.80
1 U - 4	2	11:53:00	0.00	0.00	13.00	12.32	14.18	12.66
1 U - 4	4	11:55:00	0.00	0.00	12.83	12.14	13.99	12.48
2 L - 0	1	11:56:00	0.00	0.00	12.79	12.08	13.93	12.44
2 L - 1	1	11:58:00	6.89	1.68	14.51	13.75	15.92	14.13
2 L - 1	2	11:59:00	6.89	1.68	14.52	13.75	15.91	14.13
2 L - 1	4	12:01:00	6.89	1.68	14.54	13.77	15.94	14.16
2 L - 2	1	12:03:00	13.79	3.31	16.49	15.61	18.11	16.05
2 L - 2	2	12:04:00	13.79	3.31	16.58	15.70	18.21	16.14
2 L - 2	4	12:06:00	13.79	3.31	16.65	15.79	18.29	16.22
2 L - 3	1	12:08:00	20.68	4.94	18.72	17.79	20.53	18.25
2 L - 3	2	12:09:00	20.68	4.94	18.82	17.88	20.64	18.35
2 L - 3	4	12:11:00	20.68	4.94	18.97	18.05	20.81	18.51
2 U - 1	1	12:12:30	13.79	3.31	18.43	17.52	20.27	17.98
2 U - 1	2	12:13:30	13.79	3.31	18.43	17.50	20.26	17.96
2 U - 1	4	12:15:30	13.79	3.31	18.43	17.49	20.25	17.96
2 U - 2	1	12:17:00	6.89	1.68	17.08	16.21	18.75	16.64
2 U - 2	2	12:18:00	6.89	1.68	16.97	16.12	18.66	16.54
2 U - 2	4	12:20:00	6.89	1.68	16.96	16.06	18.61	16.51
2 U - 3	1	12:21:30	0.00	0.00	13.49	12.74	14.67	13.11
2 U - 3	2	12:22:30	0.00	0.00	13.32	12.60	14.51	12.96
2 U - 3	4	12:24:30	0.00	0.00	13.16	12.45	14.35	12.81
2 U - 3	8	12:28:30	0.00	0.00	13.03	12.31	14.17	12.67

* LVWDT 20690 is not included in the average due to its orientation.
LVWDTs 20689 and 20691 are oriented 180° opposed.

Upward and Downward O-cell™ Plate Movement and Creep (calculated)
Test Shaft #2 - I-235 / 28th Street 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)
1L-0	-	10:36:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
1L-1	1	10:56:30	3.45	0.86	0.05	0.07	0.12	0.40	-0.28		
1L-1	2	10:57:30	3.45	0.86	0.10	0.06	0.17	0.41	-0.24	0.05	-0.04
1L-1	4	10:59:30	3.45	0.86	0.06	0.06	0.12	0.40	-0.28	-0.05	0.04
1L-2	1	11:01:00	6.89	1.68	0.20	0.11	0.31	0.57	-0.26		
1L-2	2	11:02:00	6.89	1.68	0.20	0.11	0.30	0.60	-0.29	-0.01	0.03
1L-2	4	11:04:00	6.89	1.68	0.31	0.10	0.41	0.63	-0.22	0.11	-0.08
1L-3	1	11:05:30	10.34	2.49	0.47	0.21	0.68	1.32	-0.64		
1L-3	2	11:06:30	10.34	2.49	0.53	0.25	0.78	1.45	-0.67	0.09	0.04
1L-3	4	11:08:30	10.34	2.49	0.62	0.29	0.92	1.86	-0.94	0.14	0.27
1L-4	1	11:10:00	13.79	3.31	1.16	0.45	1.62	3.05	-1.43		
1L-4	2	11:11:00	13.79	3.31	1.23	0.46	1.69	3.21	-1.52	0.07	0.08
1L-4	4	11:13:00	13.79	3.31	1.33	0.47	1.81	3.45	-1.64	0.11	0.12
1L-5	1	11:17:00	17.24	4.12	2.37	0.61	2.97	5.08	-2.10		
1L-5	2	11:18:00	17.24	4.12	2.48	0.61	3.09	5.25	-2.16	0.12	0.06
1L-5	4	11:20:00	17.24	4.12	2.61	0.60	3.21	5.49	-2.28	0.12	0.12
1L-6	1	11:23:00	20.68	4.94	3.85	0.72	4.57	7.42	-2.85		
1L-6	2	11:24:00	20.68	4.94	3.98	0.72	4.70	7.65	-2.95	0.13	0.10
1L-6	4	11:26:00	20.68	4.94	4.12	0.71	4.82	7.93	-3.10	0.12	0.15
1L-7	1	11:28:00	24.13	5.75	6.08	0.82	6.89	10.47	-3.58		
1L-7	2	11:29:00	24.13	5.75	6.29	0.81	7.09	10.79	-3.70	0.20	0.12
1L-7	4	11:31:00	24.13	5.75	6.93	0.82	7.74	11.56	-3.82	0.65	0.12
1L-8	1	11:33:30	27.58	6.57	12.18	0.95	13.14	17.55	-4.41		
1L-8	2	11:34:30	27.58	6.57	12.96	0.94	13.90	18.41	-4.51	0.77	0.10
1L-8	4	11:36:30	27.58	6.57	13.89	0.93	14.83	19.51	-4.68	0.93	0.17
1U-1	1	11:38:00	20.68	4.94	13.97	0.84	14.81	19.28	-4.47		
1U-1	2	11:39:00	20.68	4.94	14.02	0.84	14.86	19.28	-4.42		
1U-1	4	11:41:00	20.68	4.94	14.08	0.83	14.92	19.27	-4.35		
1U-2	1	11:42:30	13.79	3.31	13.71	0.68	14.39	18.34	-3.95		
1U-2	2	11:43:30	13.79	3.31	13.68	0.67	14.34	18.24	-3.89		
1U-2	4	11:45:30	13.79	3.31	13.52	0.67	14.19	18.21	-4.02		
1U-3	1	11:47:00	6.89	1.68	12.91	0.46	13.37	16.72	-3.35		
1U-3	2	11:48:00	6.89	1.68	12.88	0.46	13.34	16.62	-3.29		
1U-3	4	11:50:00	6.89	1.68	12.75	0.45	13.21	16.55	-3.34		
1U-4	1	11:52:00	0.00	0.00	10.97	0.13	11.10	12.80	-1.70		
1U-4	2	11:53:00	0.00	0.00	10.84	0.12	10.97	12.66	-1.69		
1U-4	4	11:55:00	0.00	0.00	10.84	0.12	10.96	12.48	-1.52		
2L-0	1	11:56:00	0.00	0.00	10.85	0.12	10.97	12.44	-1.47		
2L-1	1	11:58:00	6.89	1.68	11.20	0.31	11.51	14.13	-2.62		
2L-1	2	11:59:00	6.89	1.68	11.27	0.31	11.58	14.13	-2.55		
2L-1	4	12:01:00	6.89	1.68	11.28	0.31	11.59	14.16	-2.57		
2L-2	1	12:03:00	13.79	3.31	12.18	0.55	12.72	16.05	-3.33		
2L-2	2	12:04:00	13.79	3.31	12.25	0.55	12.80	16.14	-3.34		
2L-2	4	12:06:00	13.79	3.31	12.37	0.55	12.92	16.22	-3.30		
2L-3	1	12:08:00	20.68	4.94	13.52	0.78	14.29	18.25	-3.96		
2L-3	2	12:09:00	20.68	4.94	13.52	0.77	14.29	18.35	-4.07		
2L-3	4	12:11:00	20.68	4.94	13.50	0.77	14.27	18.51	-4.24		
2U-1	1	12:12:30	13.79	3.31	13.37	0.67	14.03	17.98	-3.94		
2U-1	2	12:13:30	13.79	3.31	13.31	0.67	13.97	17.96	-3.99		
2U-1	4	12:15:30	13.79	3.31	13.19	0.67	13.85	17.96	-4.11		
2U-2	1	12:17:00	6.89	1.68	12.72	0.46	13.18	16.64	-3.47		
2U-2	2	12:18:00	6.89	1.68	12.60	0.45	13.05	16.54	-3.49		
2U-2	4	12:20:00	6.89	1.68	12.55	0.46	13.01	16.51	-3.50		
2U-3	1	12:21:30	0.00	0.00	11.10	0.14	11.24	13.11	-1.88		
2U-3	2	12:22:30	0.00	0.00	11.01	0.13	11.14	12.96	-1.81		
2U-3	4	12:24:30	0.00	0.00	11.02	0.13	11.15	12.81	-1.66		
2U-3	8	12:28:30	0.00	0.00	11.01	0.12	11.12	12.67	-1.55		

Strain Gage Readings and Loads at Levels 1, 2 and 3
Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA

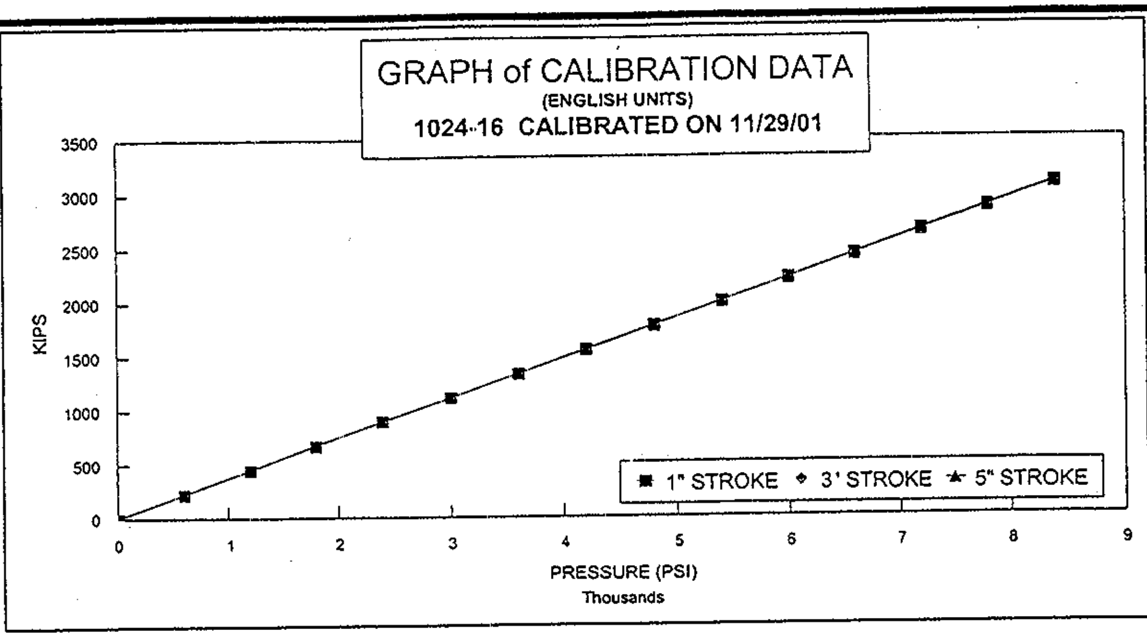
Load Test Increment	Hold Time (minutes)	Time (h:m:s)	O-cell™ Pressure (MPa)	O-cell™ Load (MN)	Level 1 23046 (με)	Level 1 23047 (με)	Level 1 Av. Load (MN)	Level 2 21376 (με)	Level 2 21377 (με)	Level 2 Av. Load (MN)	Level 3 23050 (με)	Level 3 23051 (με)	Level 3 Av. Load (MN)
1 L - 0	-	10:36:00	0.00	0.00	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
1 L - 1	1	10:56:30	3.45	0.86	17.2	11.2	0.45	6.4	5.2	0.18	2.0	1.9	0.06
1 L - 1	2	10:57:30	3.45	0.86	17.4	10.9	0.44	6.6	5.2	0.19	2.0	1.9	0.06
1 L - 1	4	10:59:30	3.45	0.86	17.6	10.5	0.44	6.6	5.1	0.18	2.0	2.2	0.07
1 L - 2	1	11:01:00	6.89	1.68	29.6	17.3	0.74	10.3	8.4	0.29	3.1	3.4	0.10
1 L - 2	2	11:02:00	6.89	1.68	30.0	17.4	0.75	10.5	8.2	0.29	3.2	3.2	0.10
1 L - 2	4	11:04:00	6.89	1.68	30.4	17.4	0.75	10.6	8.2	0.30	3.2	3.3	0.10
1 L - 3	1	11:05:30	10.34	2.49	44.6	40.8	1.34	21.8	18.6	0.64	7.7	8.1	0.25
1 L - 3	2	11:06:30	10.34	2.49	47.4	45.8	1.47	24.2	21.6	0.72	9.1	9.2	0.29
1 L - 3	4	11:08:30	10.34	2.49	58.5	49.3	1.70	28.4	25.5	0.85	11.8	11.4	0.37
1 L - 4	1	11:10:00	13.79	3.31	82.2	67.2	2.35	42.8	38.1	1.27	19.2	19.1	0.60
1 L - 4	2	11:11:00	13.79	3.31	82.5	69.3	2.39	43.4	39.0	1.30	19.8	19.5	0.62
1 L - 4	4	11:13:00	13.79	3.31	82.3	69.7	2.39	43.5	39.8	1.31	20.2	19.9	0.63
1 L - 5	1	11:17:00	17.24	4.12	104.6	87.0	3.02	55.0	50.7	1.66	26.2	25.3	0.81
1 L - 5	2	11:18:00	17.24	4.12	104.6	87.9	3.03	54.8	51.0	1.67	26.3	25.3	0.81
1 L - 5	4	11:20:00	17.24	4.12	104.5	88.6	3.04	54.6	51.8	1.67	26.4	25.2	0.81
1 L - 6	1	11:23:00	20.68	4.94	127.5	104.7	3.66	65.0	61.5	1.99	31.6	29.4	0.96
1 L - 6	2	11:24:00	20.68	4.94	127.7	104.9	3.66	64.6	61.4	1.99	31.5	29.1	0.95
1 L - 6	4	11:26:00	20.68	4.94	126.2	104.0	3.63	63.5	60.6	1.96	31.2	28.4	0.94
1 L - 7	1	11:28:00	24.13	5.75	147.8	122.1	4.25	73.4	70.9	2.27	35.6	31.7	1.06
1 L - 7	2	11:29:00	24.13	5.75	145.7	121.6	4.21	72.4	70.4	2.25	35.5	31.5	1.05
1 L - 7	4	11:31:00	24.13	5.75	148.8	125.8	4.33	73.1	72.3	2.29	35.8	31.5	1.06
1 L - 8	1	11:33:30	27.58	6.57	181.3	150.9	5.23	85.3	83.7	2.66	40.5	35.0	1.19
1 L - 8	2	11:34:30	27.58	6.57	181.4	150.2	5.22	84.1	82.4	2.62	40.0	34.0	1.17
1 L - 8	4	11:36:30	27.58	6.57	180.5	148.1	5.18	82.2	79.9	2.55	39.1	32.3	1.12
1 U - 1	1	11:38:00	20.68	4.94	164.6	131.2	4.66	75.6	73.0	2.34	36.4	29.6	1.04
1 U - 1	2	11:39:00	20.68	4.94	163.6	130.9	4.64	74.9	72.3	2.32	36.1	29.4	1.03
1 U - 1	4	11:41:00	20.68	4.94	161.8	129.6	4.59	74.1	71.7	2.30	35.8	29.0	1.02
1 U - 2	1	11:42:30	13.79	3.31	131.1	97.3	3.60	61.2	58.1	1.88	30.4	23.6	0.85
1 U - 2	2	11:43:30	13.79	3.31	128.8	95.0	3.52	60.2	57.2	1.85	30.2	23.1	0.84
1 U - 2	4	11:45:30	13.79	3.31	128.9	96.0	3.54	60.4	57.5	1.86	30.2	23.2	0.84
1 U - 3	1	11:47:00	6.89	1.68	87.5	59.0	2.31	42.3	40.2	1.30	22.5	15.3	0.60
1 U - 3	2	11:48:00	6.89	1.68	86.9	58.2	2.29	42.2	40.0	1.30	22.1	15.2	0.59
1 U - 3	4	11:50:00	6.89	1.68	86.3	57.9	2.27	41.6	39.8	1.28	21.8	15.1	0.58
1 U - 4	1	11:52:00	0.00	0.00	18.5	11.7	0.48	9.6	12.9	0.35	9.2	2.6	0.18
1 U - 4	2	11:53:00	0.00	0.00	18.2	11.3	0.46	9.3	12.7	0.35	9.0	2.2	0.18
1 U - 4	4	11:55:00	0.00	0.00	17.8	10.4	0.44	9.2	12.5	0.34	8.6	2.4	0.17
2 L - 0	1	11:56:00	0.00	0.00	17.9	10.5	0.45	9.2	12.3	0.34	8.5	2.1	0.17
2 L - 1	1	11:58:00	6.89	1.68	59.3	45.1	1.65	28.2	28.3	0.89	14.8	9.1	0.38
2 L - 1	2	11:59:00	6.89	1.68	58.8	44.7	1.63	27.8	27.9	0.88	14.7	8.8	0.37
2 L - 1	4	12:01:00	6.89	1.68	58.9	45.1	1.64	27.9	27.8	0.88	14.8	9.1	0.38
2 L - 2	1	12:03:00	13.79	3.31	103.0	83.0	2.93	50.2	46.8	1.53	23.3	18.0	0.65
2 L - 2	2	12:04:00	13.79	3.31	104.4	84.2	2.97	50.6	47.3	1.54	23.7	18.6	0.67
2 L - 2	4	12:06:00	13.79	3.31	104.2	84.4	2.97	50.4	47.2	1.54	23.7	18.2	0.66
2 L - 3	1	12:08:00	20.68	4.94	146.3	121.1	4.21	69.5	65.4	2.12	32.4	27.1	0.94
2 L - 3	2	12:09:00	20.68	4.94	145.1	120.2	4.18	68.8	64.6	2.10	32.4	26.9	0.94
2 L - 3	4	12:11:00	20.68	4.94	145.8	121.3	4.21	68.9	64.9	2.11	32.7	27.1	0.94
2 U - 1	1	12:12:30	13.79	3.31	125.6	97.7	3.52	60.1	55.8	1.83	29.0	23.2	0.82
2 U - 1	2	12:13:30	13.79	3.31	125.9	97.8	3.52	60.0	55.7	1.82	29.3	23.1	0.83
2 U - 1	4	12:15:30	13.79	3.31	125.4	97.6	3.51	60.1	55.7	1.82	29.3	23.0	0.82
2 U - 2	1	12:17:00	6.89	1.68	84.7	60.1	2.28	42.3	38.8	1.28	21.7	15.2	0.58
2 U - 2	2	12:18:00	6.89	1.68	83.3	58.6	2.24	41.6	37.5	1.25	21.4	15.1	0.58
2 U - 2	4	12:20:00	6.89	1.68	84.2	59.1	2.26	42.0	37.8	1.26	21.3	15.1	0.57
2 U - 3	1	12:21:30	0.00	0.00	17.4	12.9	0.48	9.0	11.5	0.32	8.9	2.5	0.18
2 U - 3	2	12:22:30	0.00	0.00	17.3	12.2	0.46	9.0	11.2	0.32	8.7	2.1	0.17
2 U - 3	4	12:24:30	0.00	0.00	16.9	11.2	0.44	8.9	11.1	0.31	8.3	2.2	0.16
2 U - 3	8	12:28:30	0.00	0.00	16.6	10.5	0.43	8.7	10.9	0.31	8.1	1.8	0.16

Strain Gage Readings and Loads at Levels 5 and 6
Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA

Load Test Increment	Hold Time (minutes)	Time (h:m:s)	O-cell™ Pressure (MPa)	O-cell™ Load (MN)	Level 4 23055 (με)	Level 4 23054 (με)	Level 4 Av. Load (MN)	Level 5 22915 (με)	Level 5 22916 (με)	Level 5 Av. Load (MN)			
1L-0	-	10:36:00	0.00	0.00	0.0	0.0	0.00	0.0	0.0	0.00			
1L-1	1	10:56:30	3.45	0.86	1.6	1.6	0.05	1.2	1.1	0.04			
1L-1	2	10:57:30	3.45	0.86	1.6	1.6	0.05	1.2	1.1	0.04			
1L-1	4	10:59:30	3.45	0.86	1.6	1.6	0.05	1.2	0.9	0.03			
1L-2	1	11:01:00	6.89	1.68	2.6	2.6	0.08	1.8	1.8	0.06			
1L-2	2	11:02:00	6.89	1.68	2.7	2.6	0.08	1.9	1.6	0.05			
1L-2	4	11:04:00	6.89	1.68	2.8	2.6	0.09	1.7	1.6	0.05			
1L-3	1	11:05:30	10.34	2.49	6.5	6.7	0.21	4.7	4.1	0.14			
1L-3	2	11:06:30	10.34	2.49	7.3	7.4	0.23	5.4	4.4	0.15			
1L-3	4	11:08:30	10.34	2.49	9.6	9.2	0.30	6.9	5.8	0.20			
1L-4	1	11:10:00	13.79	3.31	17.0	15.8	0.52	12.9	10.1	0.36			
1L-4	2	11:11:00	13.79	3.31	17.5	16.2	0.53	13.3	10.6	0.38			
1L-4	4	11:13:00	13.79	3.31	17.8	16.4	0.54	13.6	10.6	0.38			
1L-5	1	11:17:00	17.24	4.12	23.2	21.2	0.70	17.5	13.7	0.49			
1L-5	2	11:18:00	17.24	4.12	23.1	21.1	0.70	17.4	13.7	0.49			
1L-5	4	11:20:00	17.24	4.12	23.1	21.4	0.70	17.0	13.8	0.49			
1L-6	1	11:23:00	20.68	4.94	27.2	24.9	0.82	19.3	16.6	0.57			
1L-6	2	11:24:00	20.68	4.94	27.0	24.8	0.81	19.2	16.5	0.56			
1L-6	4	11:26:00	20.68	4.94	26.5	24.3	0.80	18.6	16.4	0.55			
1L-7	1	11:28:00	24.13	5.75	29.6	27.3	0.90	19.6	18.8	0.60			
1L-7	2	11:29:00	24.13	5.75	29.2	27.3	0.89	19.5	19.0	0.61			
1L-7	4	11:31:00	24.13	5.75	29.1	27.4	0.89	19.0	19.0	0.60			
1L-8	1	11:33:30	27.58	6.57	31.1	31.8	0.99	18.4	23.1	0.65			
1L-8	2	11:34:30	27.58	6.57	30.2	31.3	0.97	17.5	23.0	0.64			
1L-8	4	11:36:30	27.58	6.57	28.8	30.4	0.93	16.2	22.9	0.62			
1U-1	1	11:38:00	20.68	4.94	26.6	27.9	0.86	14.6	21.3	0.56			
1U-1	2	11:39:00	20.68	4.94	26.4	27.7	0.85	14.4	21.2	0.56			
1U-1	4	11:41:00	20.68	4.94	26.1	27.2	0.84	14.1	20.9	0.55			
1U-2	1	11:42:30	13.79	3.31	21.8	23.2	0.71	11.0	18.1	0.46			
1U-2	2	11:43:30	13.79	3.31	21.3	22.8	0.70	10.7	18.1	0.45			
1U-2	4	11:45:30	13.79	3.31	21.4	22.8	0.70	10.8	18.0	0.45			
1U-3	1	11:47:00	6.89	1.68	14.7	16.4	0.49	6.0	14.4	0.32			
1U-3	2	11:48:00	6.89	1.68	14.4	16.2	0.48	5.8	14.3	0.32			
1U-3	4	11:50:00	6.89	1.68	14.3	16.1	0.48	5.6	14.0	0.31			
1U-4	1	11:52:00	0.00	0.00	3.7	5.0	0.14	-1.4	6.8	0.08			
1U-4	2	11:53:00	0.00	0.00	3.8	5.0	0.14	-1.3	6.5	0.08			
1U-4	4	11:55:00	0.00	0.00	3.6	4.7	0.13	-1.4	6.3	0.08			
2L-0	1	11:56:00	0.00	0.00	3.5	4.6	0.13	-1.4	6.5	0.08			
2L-1	1	11:58:00	6.89	1.68	8.4	10.3	0.29	2.3	9.7	0.19			
2L-1	2	11:59:00	6.89	1.68	8.3	10.1	0.29	2.4	10.0	0.20			
2L-1	4	12:01:00	6.89	1.68	8.3	10.1	0.29	2.1	9.8	0.19			
2L-2	1	12:03:00	13.79	3.31	15.9	17.8	0.53	7.3	14.5	0.34			
2L-2	2	12:04:00	13.79	3.31	15.8	18.1	0.53	7.3	14.8	0.35			
2L-2	4	12:06:00	13.79	3.31	16.1	18.1	0.54	7.4	14.7	0.35			
2L-3	1	12:08:00	20.68	4.94	23.5	25.4	0.77	12.6	19.6	0.51			
2L-3	2	12:09:00	20.68	4.94	23.3	25.2	0.76	12.5	19.1	0.50			
2L-3	4	12:11:00	20.68	4.94	23.4	25.4	0.77	12.5	19.4	0.50			
2U-1	1	12:12:30	13.79	3.31	20.6	22.5	0.68	10.7	17.5	0.44			
2U-1	2	12:13:30	13.79	3.31	20.6	22.5	0.68	10.5	17.7	0.44			
2U-1	4	12:15:30	13.79	3.31	20.5	22.5	0.68	10.4	17.7	0.44			
2U-2	1	12:17:00	6.89	1.68	14.0	16.2	0.47	5.8	13.7	0.31			
2U-2	2	12:18:00	6.89	1.68	13.7	15.9	0.47	5.6	13.5	0.30			
2U-2	4	12:20:00	6.89	1.68	13.7	15.9	0.47	5.5	13.8	0.30			
2U-3	1	12:21:30	0.00	0.00	3.8	4.9	0.14	-1.6	6.7	0.08			
2U-3	2	12:22:30	0.00	0.00	3.4	4.8	0.13	-1.8	6.7	0.08			
2U-3	4	12:24:30	0.00	0.00	3.3	4.6	0.12	-1.8	6.5	0.07			
2U-3	8	12:28:30	0.00	0.00	3.2	4.3	0.12	-1.9	6.0	0.06			

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
600	220	223	220
1200	446	448	446
1800	667	670	671
2400	895	892	888
3000	1114	1112	1110
3600	1335	1336	1331
4200	1556	1552	1546
4800	1778	1773	1766
5400	1995	1992	1986
6000	2212	2209	2198
6600	2431	2427	2415
7200	2652	2648	2636
7800	2866	2858	2851
8400	3080	3077	3064

26" O-CELL, SERIAL # 1024-16

LOAD CONVERSION FORMULA

LOAD = PRESSURE * 0.3664 + (10.7)
{KIPS} {PSI}

Regression Output:

Constant	10.715
X Coefficient	0 366
R Squared	1 000
No of Observations	42
Degrees of Freedom	40
Std Err of Y Est	11 707
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: 20689

Mfg Number: 02-496

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	2525	2523	2524		-0.25
1.200	3779	3779	3779	1255	0.11
2.400	5016	5015	5016	1237	0.17
3.600	6247	6245	6246	1231	0.13
4.800	7470	7470	7470	1224	-0.01
6.000	8694	8693	8694	1224	-0.17

Calibration Factor (C): 0.0009733 (Inches/ Digit)

Regression Zero: 2539

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B": 5529

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: 20690

Mfg. Number: 02-497

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	2498	2497	2498		-0.21
1.200	3760	3760	3760	1263	0.14
2.400	5003	5002	5003	1243	0.17
3.600	6226	6229	6228	1225	-0.09
4.800	7480	7483	7482	1254	0.12
6.000	8706	8705	8706	1224	-0.15

Calibration Factor (C): 0.0009671 (Inches/ Digit)

Regression Zero: 2510

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B": 5556

or

Position "F":

Date: March 15, 2002

Temperature: 23.2 °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: 20691

Mfg. Number: 02-498

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	2570	2570	2570		-0.23
1.200	3825	3827	3826	1256	0.10
2.400	5066	5067	5067	1241	0.18
3.600	6299	6300	6300	1233	0.13
4.800	7524	7528	7526	1227	-0.01
6.000	8753	8752	8753	1227	-0.16

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

Regression Zero: 2584

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B": 5546

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: 21376

Customer: Loadtest Inc.

Job Number: 17504

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 23.6 °C

Calibration Date: August 27, 2001

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

Cable Length: 80 ft.

Factory Zero Reading: 6833

Regression Zero: 6864

Technician: MLC

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6916	6909	6913		
1,500	7572	7562	7567	655	-0.04
3,000	8278	8267	8273	706	0.01
4,500	8985	8976	8981	708	0.14
6,000	9685	9674	9680	699	-0.04
100	6912				

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

Gage Factor:

0.356 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: 21377

Customer: Loadtest Inc.

Job Number: 17504

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 23.7 °C

Calibration Date: August 27, 2001

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

Cable Length: 80 ft.

Factory Zero Reading: 6872

Regression Zero: 6889

Technician: MLC

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6953	6949	6951		
1,500	7624	7619	7622	671	-0.34
3,000	8368	8363	8366	744	-0.30
4,500	9126	9120	9123	758	0.20
6,000	9865	9862	9864	741	0.13
100	6949				

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: 22915

Customer: Loadtest Inc.

Job Number: 18247

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 22.4 °C

Calibration Date: Febuary 5, 2002

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

Cable Length: 50 ft.

Factory Zero Reading: 7252

Regression Zero: 7255

Technician: MLC

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7310	7307	7309		
1,500	7983	7987	7985	677	-0.23
3,000	8727	8733	8730	745	0.05
4,500	9470	9470	9470	740	0.16
6,000	10203	10198	10201	731	-0.05
100	7308				

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	Calibration Date:	Febuary 5, 2002
Serial Number:	22916	Cal Std. Control Numbers:	85888-1, 398
Customer:	Loadtest Inc.	Cable Length:	50 ft.
Job Number:	18247	Factory Zero Reading:	6970
Cust. I.D. #:	n/a	Regression Zero:	6978
Prestress:	35,000 psi		
Temperature:	22.2 °C	Technician:	MLC

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7028	7026	7027		
1,500	7715	7713	7714	687	0.02
3,000	8448	8454	8451	737	0.08
4,500	9187	9186	9187	736	0.08
6,000	9919	9918	9919	732	-0.03
100	7030				

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: 23046

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: 6808

Regression Zero: 6826

Technician: KDB

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6877	6875	6876		
1,500	7547	7551	7549	673	-0.16
3,000	8283	8290	8287	738	0.18
4,500	9015	9016	9016	729	0.23
6,000	9740	9724	9732	717	-0.15
100	6876				

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 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: 23047

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: 90 ft.

Factory Zero Reading: 6791

Regression Zero: 6805

Technician: KDB

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6857	6856	6857		
1,500	7544	7549	7547	690	-0.20
3,000	8306	8305	8306	759	0.18
4,500	9058	9053	9056	750	0.27
6,000	9791	9788	9790	734	-0.18
100	6857				

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

Gage Factor:

0.341 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: 23050

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: 6955

Regression Zero: 6985

Technician: KOB

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7040	7031	7036		
1,500	7739	7736	7738	702	-0.15
3,000	8505	8498	8502	764	0.08
4,500	9270	9268	9269	768	0.43
6,000	10003	10005	10004	735	-0.29
100	7032				

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

Gage Factor:

0.338 **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 traccable 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 14, 2002
Serial Number:	23051	Cal. Std. Control Numbers:	85888-1, 25167
Customer:	Loadtest Inc.	Cable Length:	80 ft.
Job Number:	18442	Factory Zero Reading:	6978
Cust. I.D. #:	n/a	Regression Zero:	7009
Prestress:	35,000 psi		
Temperature:	23.4 °C	Technician:	KDB

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7065	7058	7062		
1,500	7750	7750	7750	689	-0.19
3,000	8509	8504	8507	757	0.13
4,500	9255	9259	9257	751	0.26
6,000	9996	9988	9992	735	-0.14
100	7058				

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

Gage Factor:

0.341 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	Calibration Date:	March 14, 2002
Serial Number:	23054	Cal. Std. Control Numbers:	85888-1, 25167
Customer:	Loadtest Inc.	Cable Length:	70 ft.
Job Number:	18442	Factory Zero Reading:	7146
Cust. I.D. #:	n/a	Regression Zero:	7153
Prestress:	35,000 psi	Technician:	KDB
Temperature:	23.6 °C		

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7206	7205	7206		
1,500	7893	7906	7900	694	-0.14
3,000	8648	8663	8656	756	0.03
4,500	9408	9409	9409	753	0.10
6,000	10155	10155	10155	747	-0.04
100	7209				

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 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: 23055

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: 70 ft.

Factory Zero Reading: 7199

Regression Zero: 7213

Technician: KDB

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7263	7263	7263		
1,500	7966	7959	7963	700	-0.16
3,000	8730	8724	8727	765	0.18
4,500	9485	9481	9483	756	0.23
6,000	10225	10223	10224	741	-0.21
100	7262				

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

Gage Factor:

0.339 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)

<u>Introduction</u>: 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

<u>Assumptions</u>: 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 <u>Procedure Part I</u>. We then use the following <u>Procedure Part II</u> 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.

<u>Procedure Part I</u>: Please refer to the attached <u>Figure A</u> showing O-cell™ test results and to <u>Figure B</u>, 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 <u>Figure A</u> and the same 0.40 inches downward in <u>Figure B</u>

<u>Note:</u> This report shows the O-cell movement data in a Figure similar to <u>Fig. A</u>, but uses the gross loads as obtained in the field. <u>Fig. A</u> uses <u>net</u> loads to make it easier for the reader to convert <u>Fig. A</u> into <u>Fig. B</u> without the complication of 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 centroid 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 centroid 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

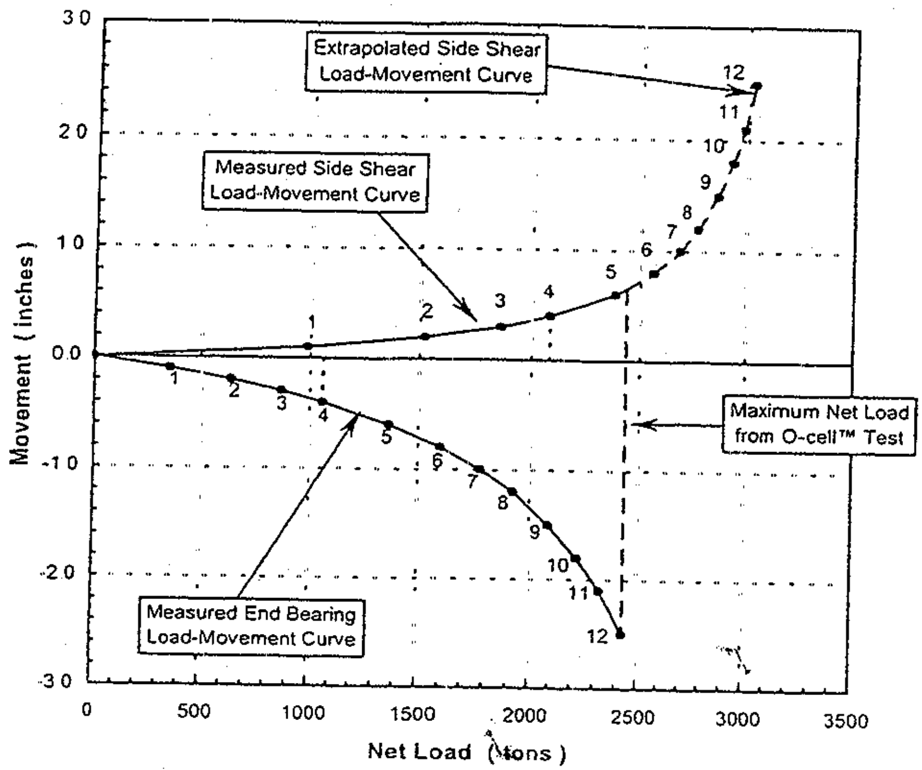
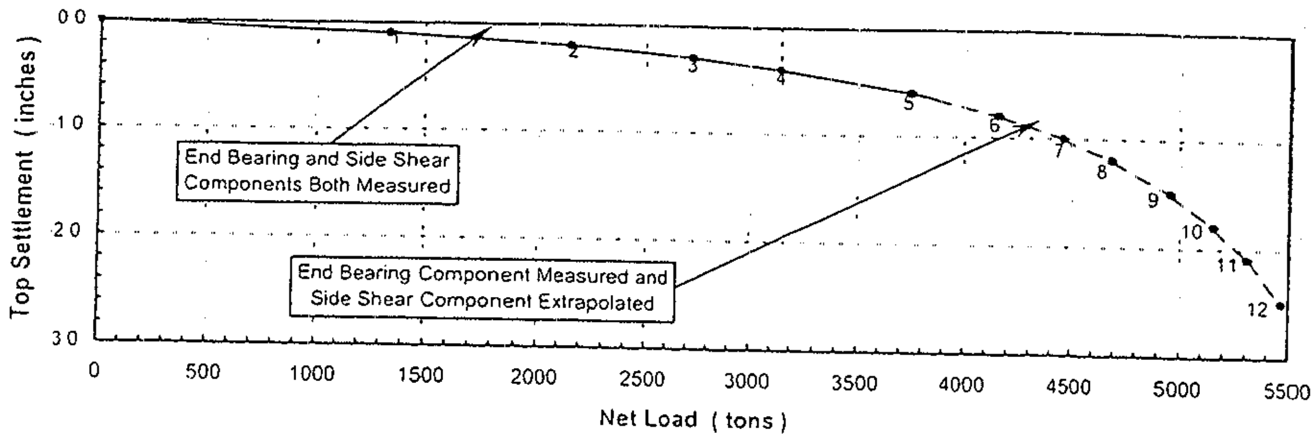
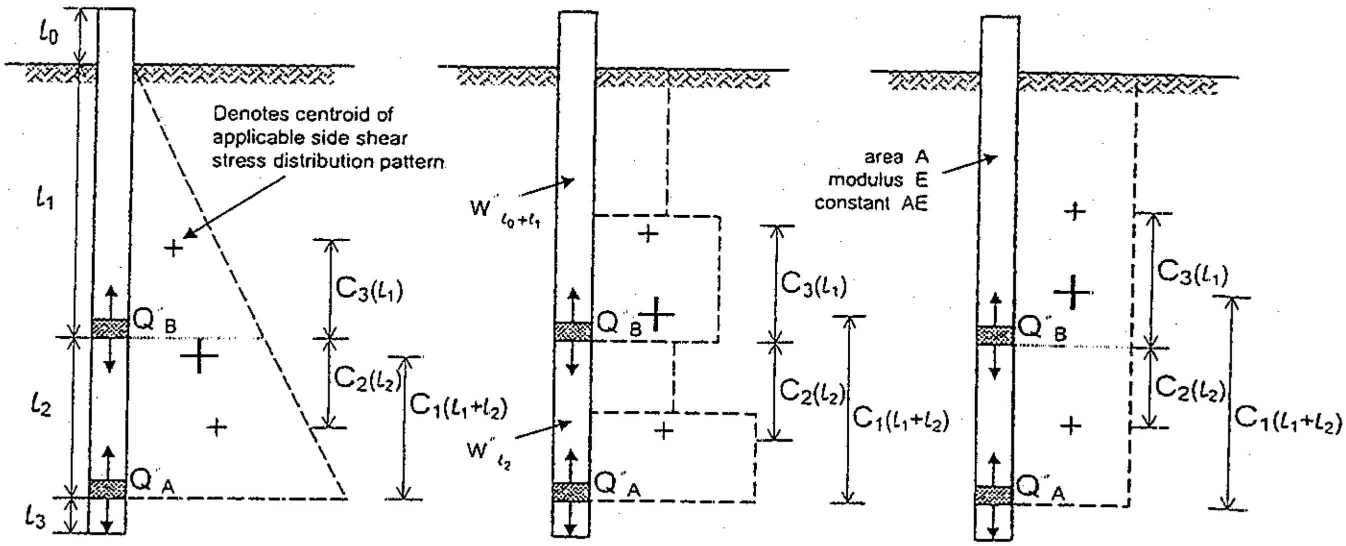


Figure B



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



1-Stage Single Level Test (Q''_A only): $\delta_{OLT} = \delta_{\uparrow(\ell_1+\ell_2)}$

$C_1 = \frac{1}{3}$	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): $\delta_{OLT} = \delta_{\uparrow\ell_1} + \delta_{\downarrow\ell_2}$

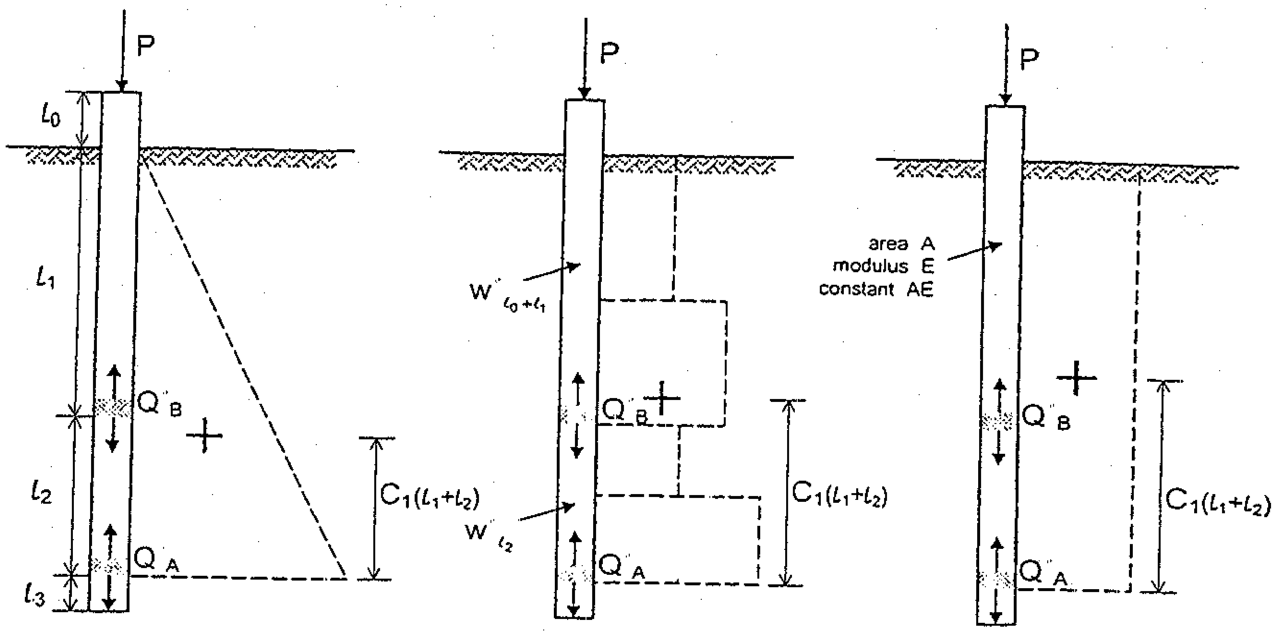
$C_3 = \frac{1}{3}$	Centroid Factor = C_3	$C_3 = \frac{1}{2}$
$\delta_{\uparrow\ell_1} = \frac{1}{3}\frac{Q''_{\uparrow B}\ell_1}{AE}$	$\delta_{\uparrow\ell_1} = C_3\frac{Q''_{\uparrow B}\ell_1}{AE}$	$\delta_{\uparrow\ell_1} = \frac{1}{3}\frac{Q''_{\uparrow B}\ell_1}{AE}$
$C_2 = \frac{1}{3}\left(\frac{3\ell_1+2\ell_2}{2\ell_1+\ell_2}\right)$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

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

Component loads Q selected at the same (±) Δ_{OLT}

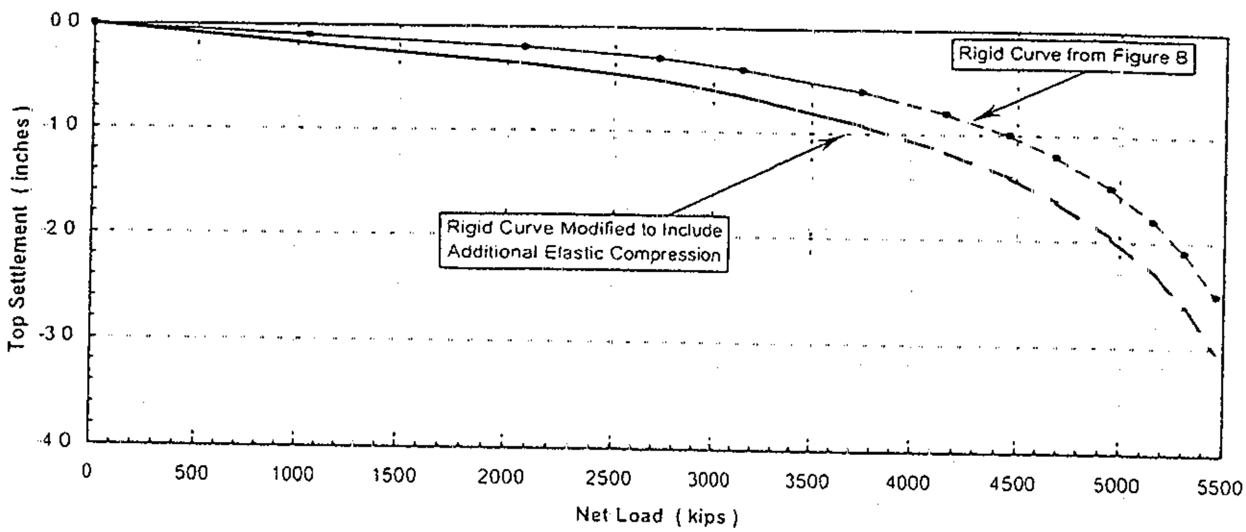
Example Calcuation for the Additional Elastic Compression Correction for Single Level Test (English Units)

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)

Δ_{OLT} (in)	$Q'_{\downarrow A}$ (kips)	Q'_{TA} (kips)	P (kips)	δ_{TLT} (in)	δ_{OLT} (in)	Δ_δ (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



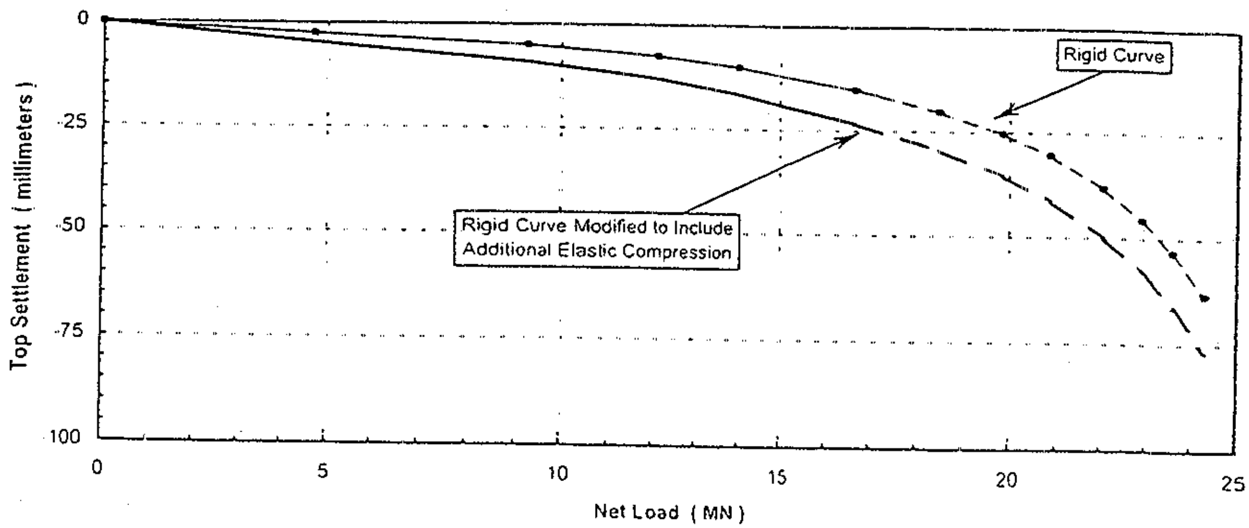
Example Calcuation for the Additional Elastic Compression Correction for Single Level Test (SI Units)

Given:

C_1 = 0 441
AE = 17000 MN (assumed constant throughout test)
ℓ_0 = 1 80 m
ℓ_1 = 14.69 m (embedded length of shaft above O-cell™)
ℓ_2 = 0 00 m
ℓ_3 = 0.00 m
Shear reduction factor = 1.00 (cohesive soil)

Δ_{OLT} (mm)	Q'_{LA} (MN)	Q'_{TA} (MN)	P (MN)	δ_{TLT} (mm)	δ_{OLT} (mm)	Δ_δ (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



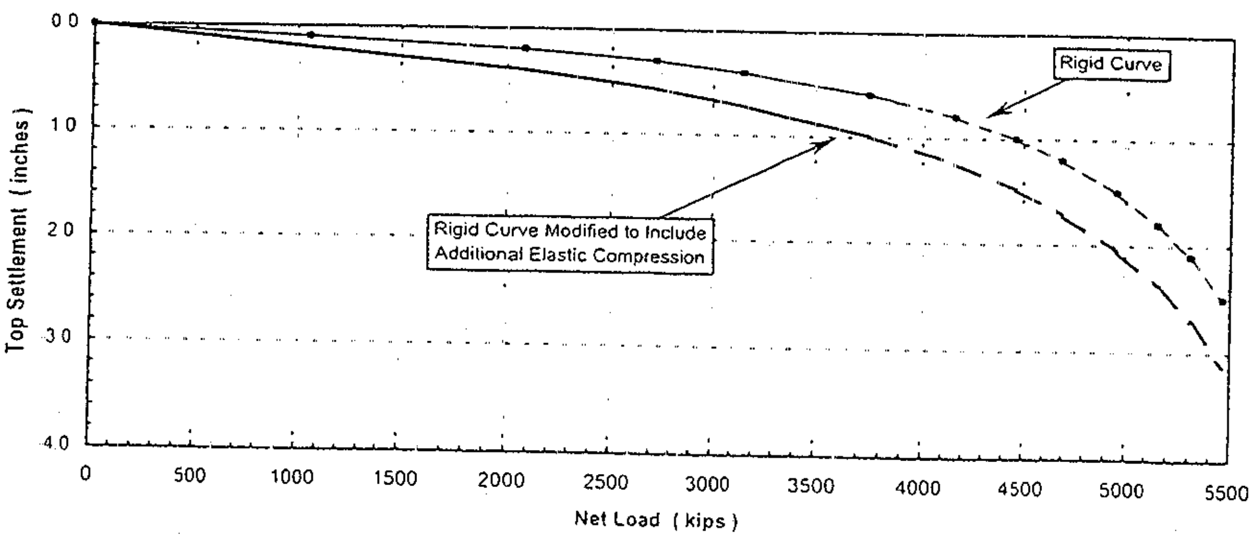
Example Calcuation for the Additional Elastic Compression Correction for Multi Level Test (English Units)

Given:

C_1 = 0 441
C_2 = 0 579
C_3 = 0 396
AE = 3820000 kips (assumed constant throughout test)
ℓ_0 = 5.9 ft
ℓ_1 = 30.0 ft (embedded length of shaft above mid-cell)
ℓ_2 = 18 2 ft (embedded length of shaft between O-cells™)
ℓ_3 = 0.0 ft
Shear reduction factor = 1 00 (cohesive soil)

Δ_{OLT} (in)	$Q'_{\downarrow A}$ (kips)	$Q'_{\downarrow B}$ (kips)	Q'_{TB} (kips)	P (kips)	δ_{TLT} (in)	δ_{OLT} (in)	Δ_δ (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)

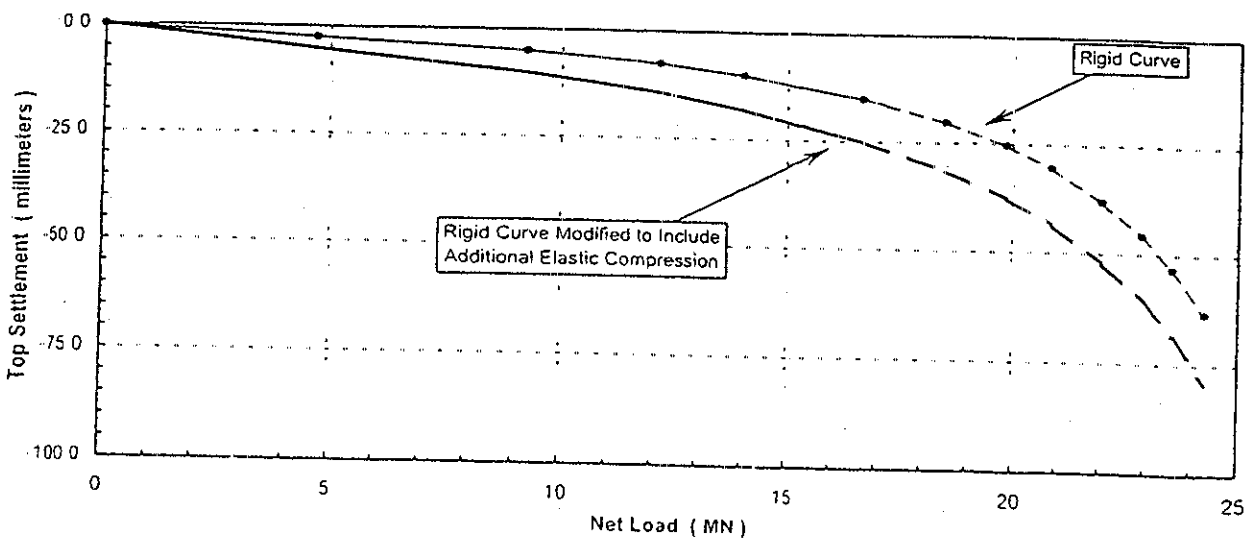
Given:

$C_1 =$ 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)

Δ_{OLT} (in)	$Q'_{\downarrow A}$ (kips)	$Q'_{\downarrow B}$ (kips)	Q'_{TB} (kips)	P (kips)	δ_{TLT} (in)	δ_{OLT} (in)	Δ_δ (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.

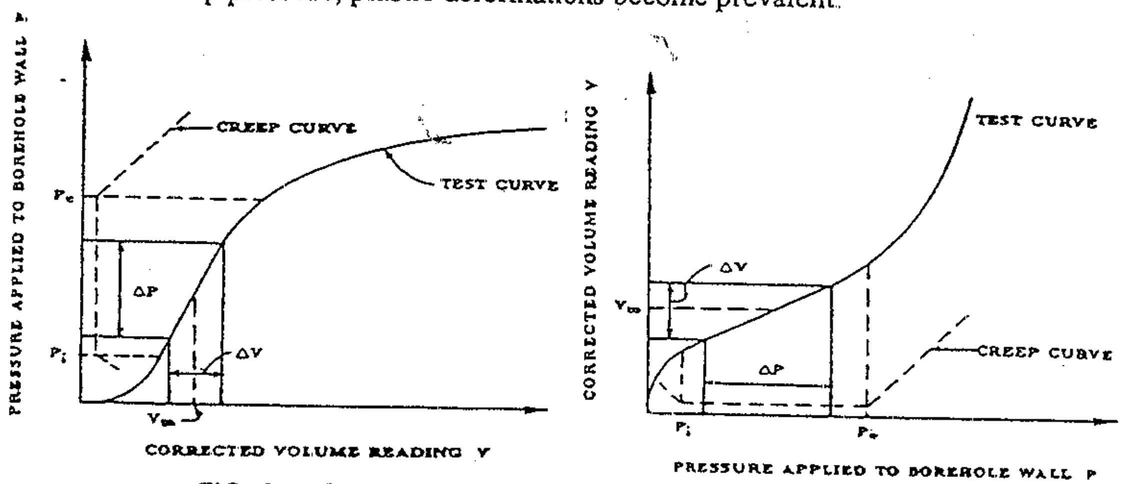


FIG. 8 Pressuremeter Test Curves for Procedure A

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. 3[rd] 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 LOGS

BORING LOG No. TB-3

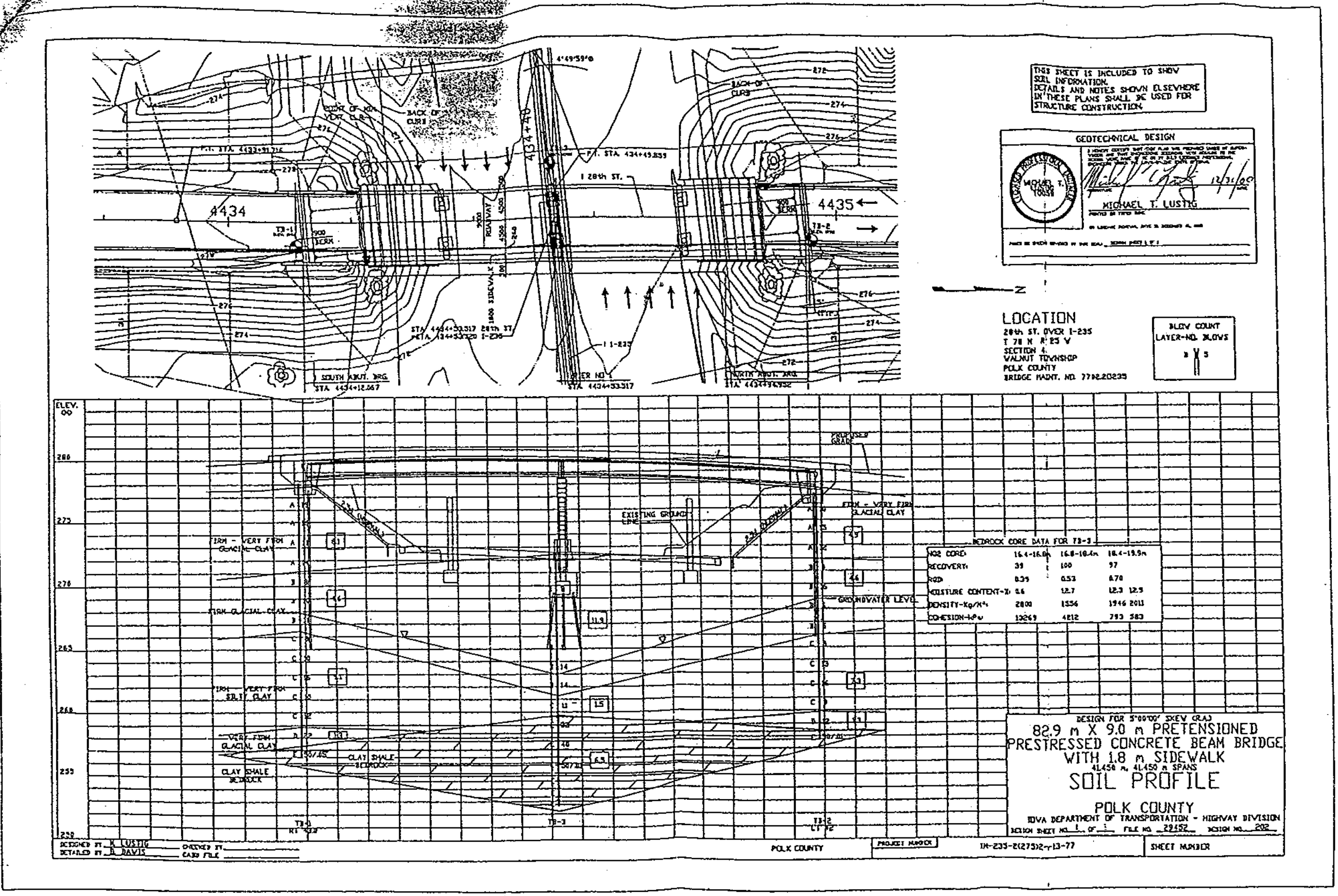
BORING NO.	LOCATION OF BORING	ELEVATION	DATUM	DRILLER	LOGGER
TB-3	I-235 Median at 28th Street	272.5m	I-235	DAH	MTL

WATER LEVEL OBSERVATIONS				TYPE OF SURFACE	DRILL RIG
WHILE DRILLING	END OF DRILLING	24 HOURS AFTER DRILLING		Grass	B-57
				DRILLING METHOD	TOTAL DEPTH
9.45m	NA			0m to 16.38m 83mm HSA, 16.38m to 19.89m NQ 2 Core	19.89m

DEPTH (M)	SAMPLE NO. & TYPE	"N" BLOWS 30 CM	% REC	SOIL DESCRIPTION: COLOR, MOISTURE, CONSISTENCY, GEOLOGIC DESCRIPTION & OTHER REMARKS	USCS CLASS	% MC	DRY DENS kg/m3	Qu Kg/cm2	DEPTH (M)
				Dark brown and brown mixed. Damp to Moist FIRM GLACIAL CLAY					
	S-1	22				17.2			
2.2									2.2
	S-2	8				17 9			
4.4	S-3	7				24 0			4.4
				Dark gray below 4.9m					
	S-4	9			CL	25 7			
6.6									6.6
	S-5	11				27.7			
8.8	S-6	14				26.9			8.8
	S-7	14				22.2			
11									11
	S-8	11		11 9 — Dark gray, Moist FIRM SILTY CLAY	CL-ML	38.3			
13.2									13.2
	S-9	33		13 4 — Dark gray and light gray, Moist CLAY SHALE BEDROCK		20.5			
15.4	S-10	40		Black and gray below 14.8m		14.7			15.4
	S-11	50				21.7			
	NQ		39	NQ Core Run 1 REC=39 RQD=0 39		0.6	2800	271 3	
				NQ Core Run 2 REC=100 RQD=0 53					
17.6	NQ		100			12 7	1556	85 9	17.6
						12 3	1946	16 2	
				NQ Core Run 3 REC=97 RQD=0 7					
	NQ		97			12 9	2011	11 9	
19.8				BEDROCK					19.8
				19 9 — Bottom of Boring @ 19 9m					
22									22

Geotechnical Services Inc.
2853 99th Street, Des Moines, IA 50322-3856
(515) 270-6542 FAX (515) 270-1911

PROJECT: 28th St - I-235 Bridge
LOCATION: I-235 and 28th St, West Des Moines, IA
JOB NO.: 006079
DATE: 9/15/00


THIS SHEET IS INCLUDED TO SHOW SOIL INFORMATION. DETAILS AND NOTES SHOWN ELSEWHERE IN THESE PLANS SHALL BE USED FOR STRUCTURE CONSTRUCTION.
GEOTECHNICAL DESIGN
MICHAEL T. LUSTIG
LOCATION
28th ST. OVER I-235
T 78 N R 25 W
SECTION 4,
WALNUT TOWNSHIP
POLK COUNTY
BRIDGE MAINT. NO. 7792.2023S
BLOW COUNT
LAYER-NO. BLOWS
4434
4435
P.I. STA. 4434+49.859
I 28th ST.
SOUTH ABUT. BRG.
NORTH ABUT. BRG.
ELEV.
EXISTING GROUND LINE
PROPOSED GRADE
FIRM - VERY FIRM GLACIAL CLAY
FIRM GLACIAL CLAY
FIRM - VERY FIRM SILTY CLAY
VERY FIRM GLACIAL CLAY
CLAY SHALE BEDROCK
GROUNDWATER LEVEL
BEDROCK CORE DATA FOR TB-3
NQ2 CORE: 16.4-16.8m 16.8-18.4m 18.4-19.9m
RECOVERY: 39 100 97
RQD: 0.39 0.53 0.70
MOISTURE CONTENT-%: 8.6 12.7 12.3 12.5
DENSITY-Kg/M³: 2800 1556 1946 2011
COHESION-kPa: 13269 4812 793 583
DESIGN FOR 5°00'00" SKEW (RAJ)
82.9 m X 9.0 m PRETENSIONED
PRESTRESSED CONCRETE BEAM BRIDGE
WITH 1.8 m SIDEWALK
41.450 m, 41.450 m SPANS
SOIL PROFILE
POLK COUNTY
IOWA DEPARTMENT OF TRANSPORTATION - HIGHWAY DIVISION
FILE NO. 29452 DESIGN NO. 202
DESIGNED BY M. LUSTIG
DETAILED BY D. DAVIS
CHECKED BY
CADD FILE
POLK COUNTY
PROJECT NUMBER
IM-235-2(275)2--13-77
SHEET NUMBER

Form 610010
7-94
METRIC

DATE MO DA YR 070202

Iowa Department of Transportation

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

TEST HOLE NUMBER	STATION	Ç ORDINATE LT CL RT	DIST	SURFACE ELEVATION	DEPTH TO WATER METERS	TO METERS		DESCRIPTION OF MATERIAL	JOB NO.	CARD NO.
P-3413	43451	RT	2	222.500	3.00	1.20	A	STIFF GR BR SILTY CLAY F		
PIER- [illegible]					DRY			ILL		
						7.90	B	STIFF TO FIRM GR SILTY G		
								LACIAL CLAY		
						10.36	C	STIFF GR SILTY CLAY WITH		
								OCC BOULDERS? (NOTE: QUES		
								TION ON BOULDER CALL - PO		
								SSIBLE PILE END ?)		
Something Else, Pile						11.58	D	SOFT GR SILTY CLAY		
End? Unknown?						12.60	E	STIFF TO FIRM GR SILTY G		
								LACIAL CLAY		
						14.00	F	POOR QUALITY OR REWORKED		
								SHALE		
						16.80	G	SHALE WITH OCC HARD SEAM		
								S		
						22.60	H	HARD SHALE WITH OCC COAL		
								SEAMS		

TO BE CODED BY BRIDGES & STRUCTURES

CONTROL CARD FOR SOILS PLOTTING
BY COMPUTER. RUN PROGRAM # 224012.
TO BE CODED BY BRIDGES & STRUCTURES
CHGE. CODE 80-
NAME:
PHONE:

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

COUNTY Polk
TOWNSHIP 78 N
RANGE 25 W
SECTION 4

City of West Des Moines

PROJECT IM-235-2(275)2-13-77
DESIGN NO.
FILE NO. ROUTE NO. I-235
TYPE AND SIZE OF BRIDGE: 82.9m X 9.0m
P.P. Conc. Bm w/1.85 Walk
BRIDGE OVER: I-235 (28th ST)

AT STATION 434+53.5
ELEVATION — STREAM BED
ELEVATION — FTG.
PAGE 1 OF 2

John D Christy
CHIEF OF PARTY

Form 610010
7-94
METRIC

DATE MO DA YR 10 02 02

Iowa Department of Transportation

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

TEST HOLE NUMBER	STATION	℄ ORDINATE LT CL RT	DIST	SURFACE ELEVATION	DEPTH TO WATER METERS	TO METERS		DESCRIPTION OF MATERIAL	JOB NO.	CARD NO.
P-3414	434+59	RT	2	272.500	WASH	1.60	A	STIFF TO FIRM GR BR SILT		
PIER-1					BORE			Y GLACIAL CLAY + SILTY C		
								LAY MIXED FILL		
						8.20	B	STIFF TO FIRM GR BR SILT		
								Y GLACIAL CLAY		
						11.60	C	STIFF GR SILTY CLAY		
						12.60	D	FIRM SILTY GLACIAL CLAY		
						13.70	E	POOR QUALITY OR REWORKED		
								SHALE		
						16.80	F	SHALE WITH OCC HARD SEAM		
								S		
						21.20	G	HARD SHALE WITH OCC COAL		
								SEAMS		

TO BE CODED BY BRIDGES & STRUCTURES

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

CHGE. CODE 80-

NAME:

PHONE:

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

COUNTY Polk

TOWNSHIP 78 N

RANGE 25 W

SECTION 4

City OF West Des Moines

PROJECT IM-235-2(225)2-13-77

DESIGN NO.

FILE NO. ROUTE NO. I-235

TYPE AND SIZE OF BRIDGE: 82.9m x 9.0m P.P. Conc. Bm w/1.85 Wlk

BRIDGE OVER: 28th St Over I-235

AT STATION 434+53.5

ELEVATION — STREAM BED

ELEVATION — FTG.

PAGE 2 OF 2

John O Chester

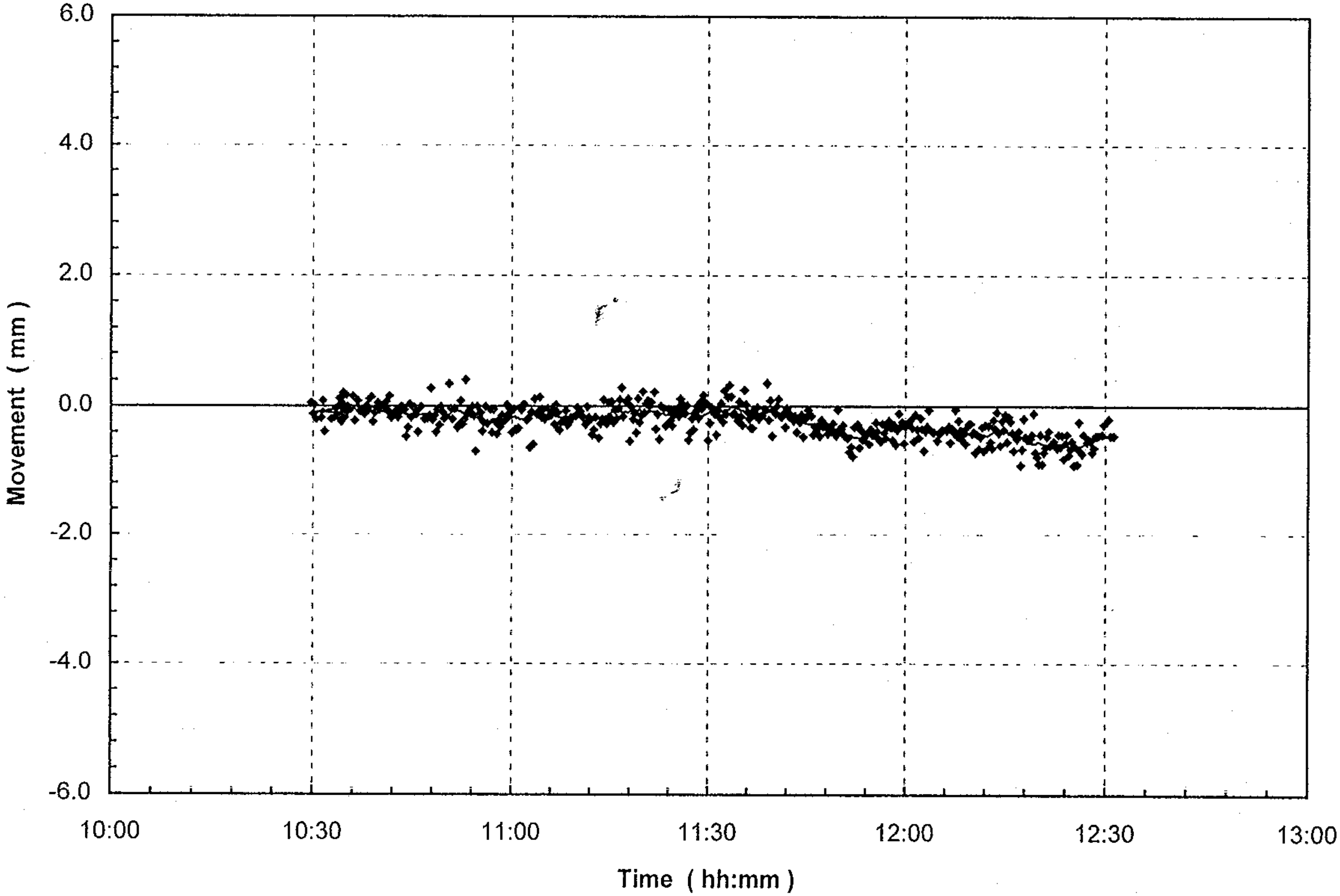
CHIEF OF PARTY

APPENDIX F

REFERENCE BEAM MONITORING

Reference Beam Monitoring

Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA

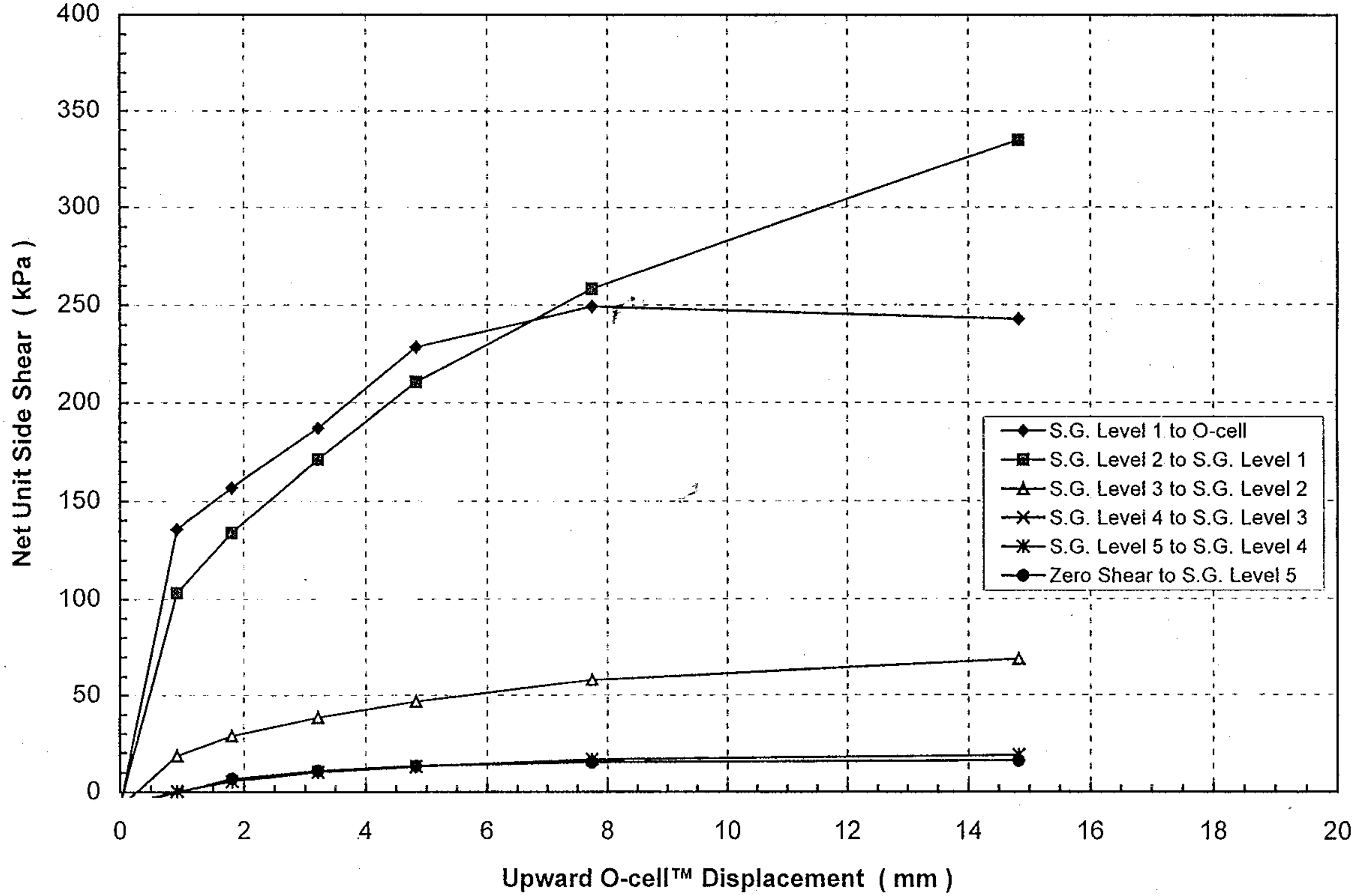


APPENDIX G

NET UNIT SHEAR CURVES AND UNIT END BEARING CURVE

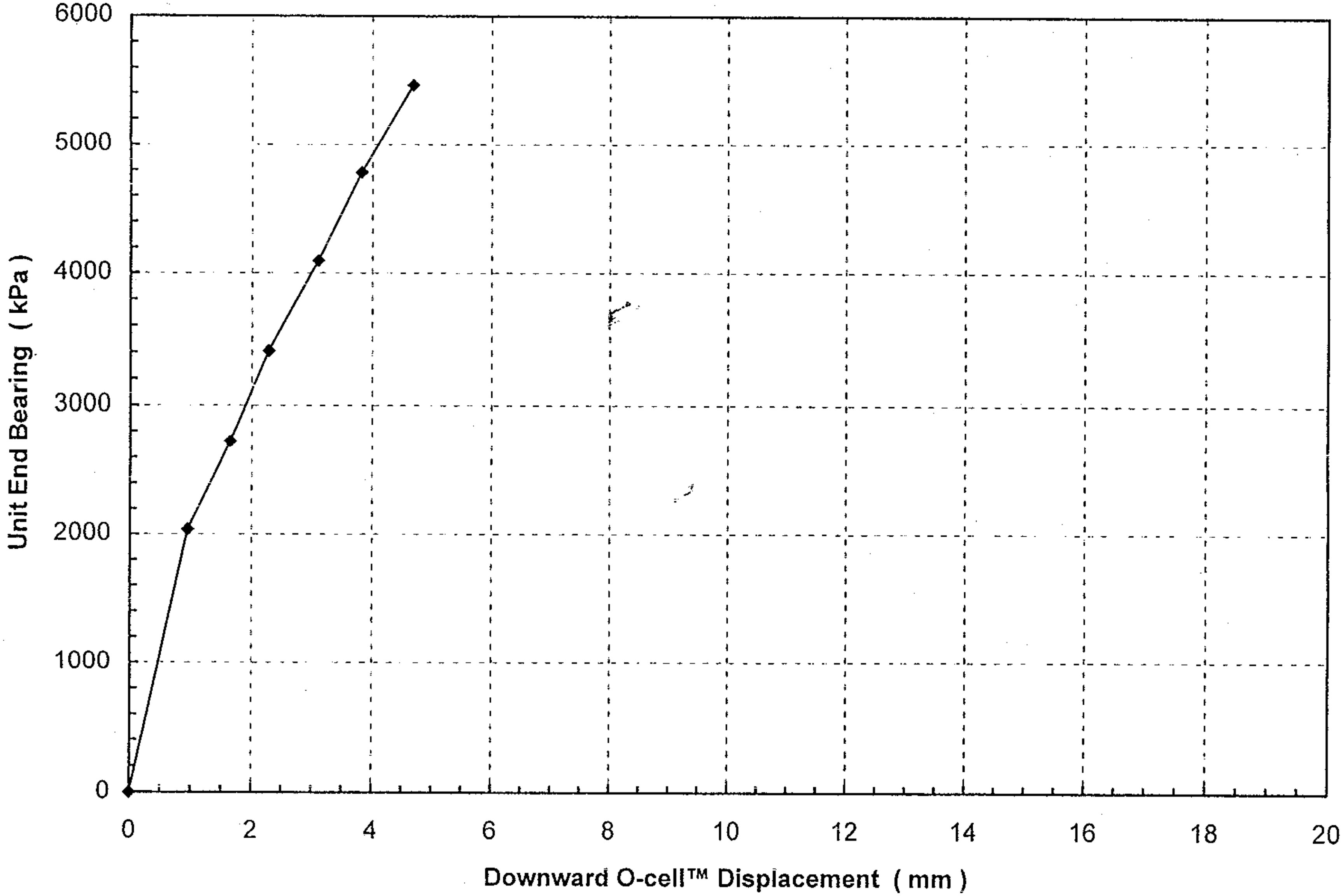
Net Unit Side Shear Curves

Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA



Unit End Bearing

Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA



APPENDIX H

HYPERBOLIC CURVE FITTING

Hyperbolic Curve Fit

Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA

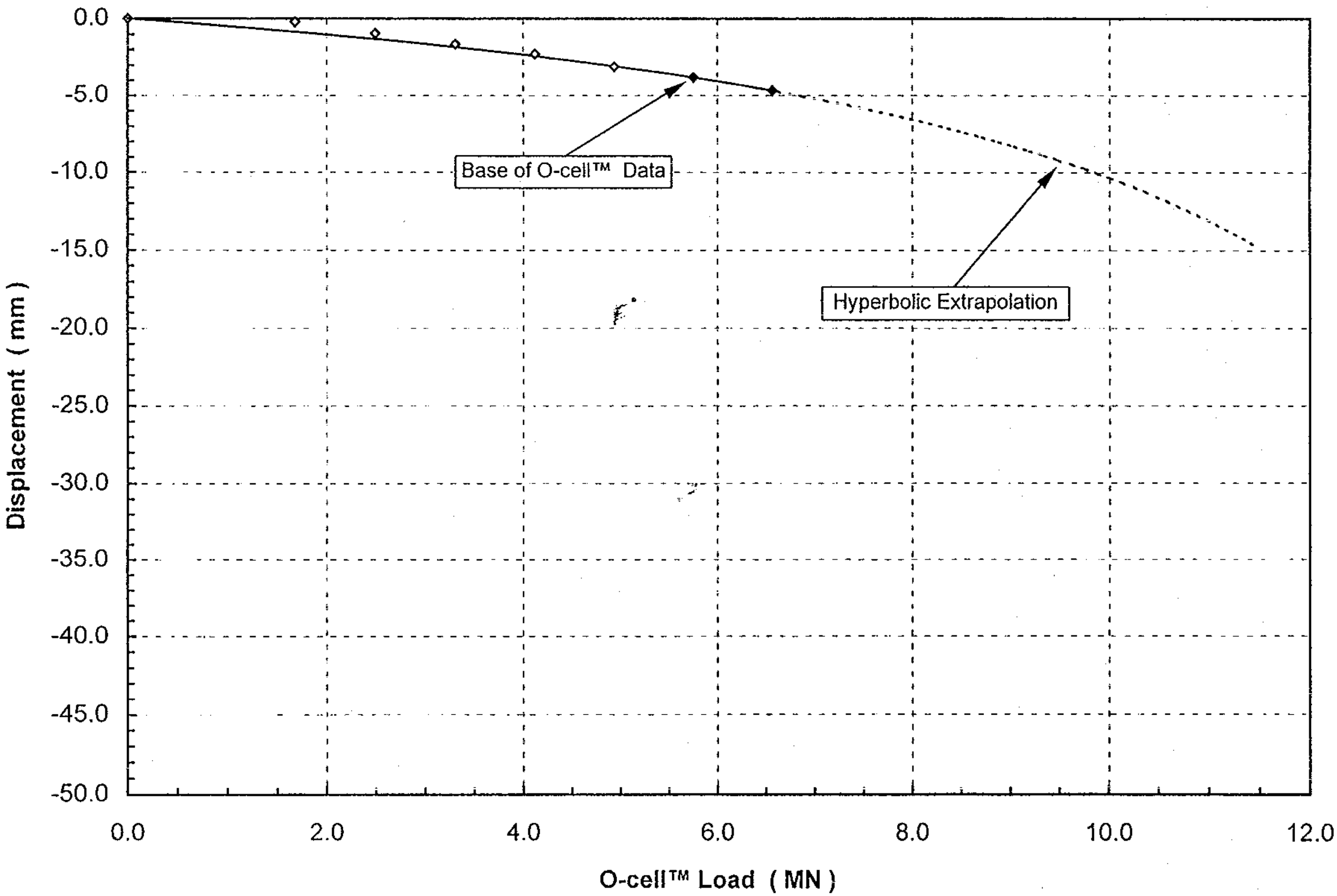
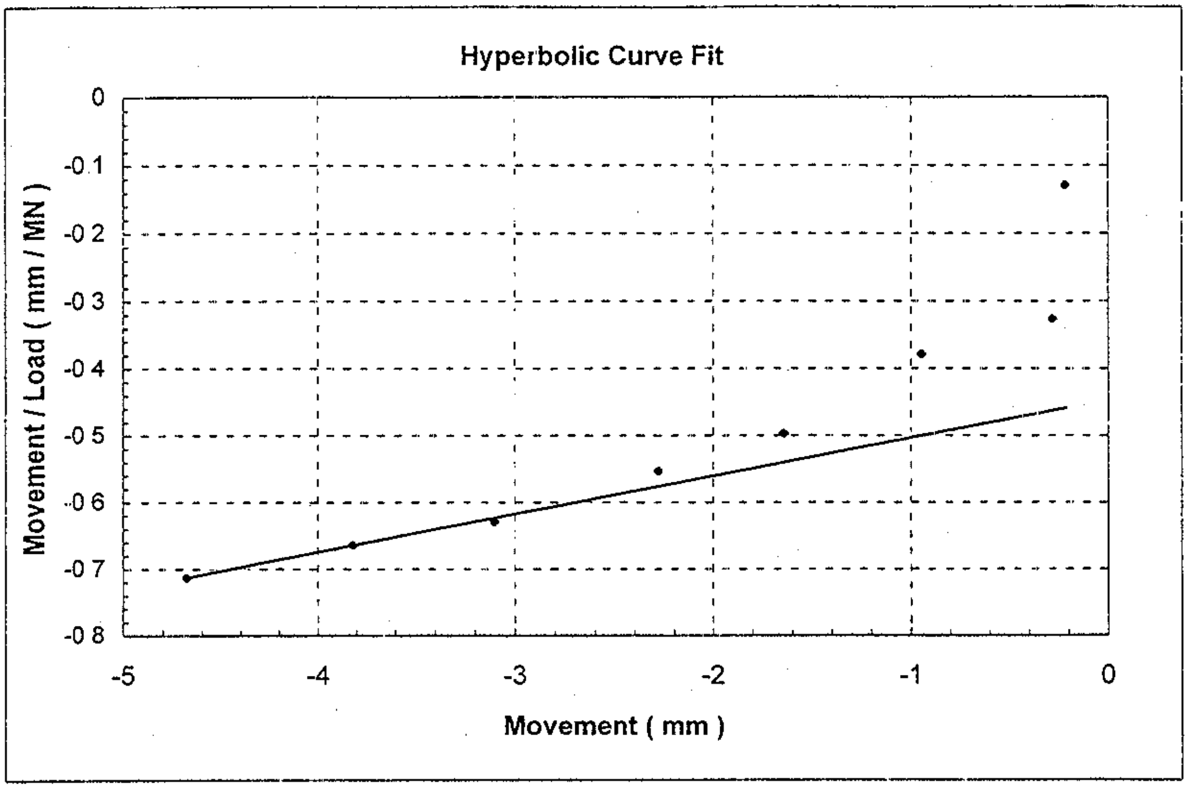


Table H-1: Hyperbolic Curve Fit of Downward Base of O-cell™ Movement

Gross Load (MN)	Down* (mm)	Y_d* (mm/MN)	$Y_{d\ calc}$ (mm/MN)	Gross Load$_{calc}$ (MN)
0.00	0.00	-	-	-
0.86	-0.28	-0.326	-0.462	0.61
1.68	-0.22	-0.129	-0.459	0.47
2.49	-0.94	-0.379	-0.500	1.89
3.31	-1.64	-0.497	-0.540	3.04
4.12	-2.28	-0.553	-0.576	3.96
4.94	-3.10	-0.628	-0.623	4.98
5.75	-3.82	-0.664	-0.664	5.75
6.57	-4.68	-0.713	-0.713	6.57

* 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 001205833	0 001205833	0	#NUM!
Residual	0	7 51883E-31	65535		
Total	1	0.001205833			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0 44642573	0	65535	#NUM!	-0 44642573	-0 44642573	-0 44642573	-0 44642573
X Variable 1	0.056893549	0	65535	#NUM!	0.056893549	0.056893549	0.056893549	0.056893549

APPENDIX I

SHAFT STIFFNESS ESTIMATION

Tangent Pile Stiffness Analysis

Test Shaft #2 - I-235 / 28th Street Overpass - Des Moines, IA

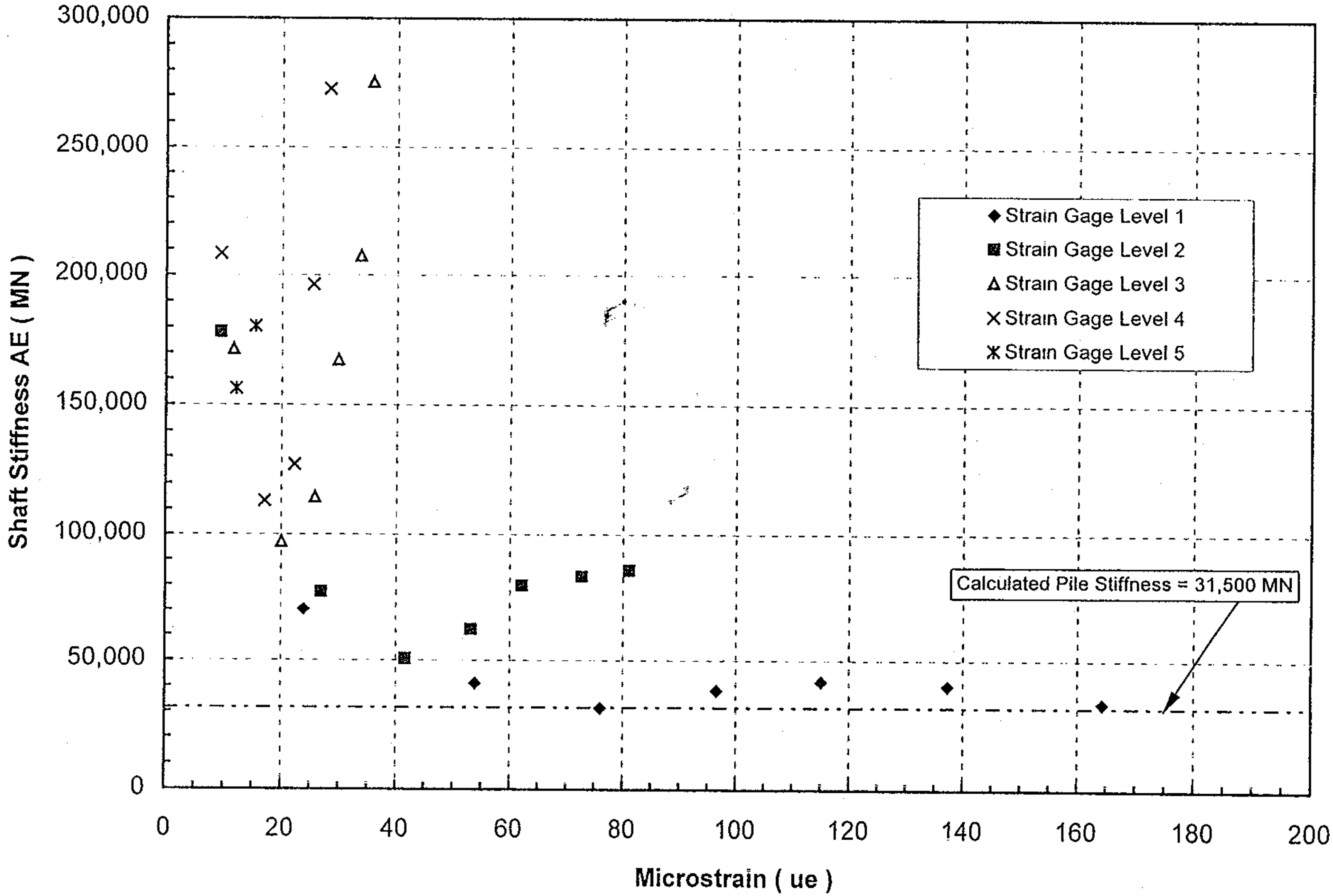


Table I-1: Tangent Stiffness Analysis for Strain Gage Levels 1 through 5

O-cell™		Strain Gage Level 1			Strain Gage Level 2			Strain Gage Level 3			Strain Gage Level 4			Strain Gage Level 5		
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)	μ Strain (με)	Δ μ Strain (με)	AE* (MN)	μ Strain (με)	Δ μ Strain (με)	AE* (MN)
0.0		0.0			0.0			0.0			0.0			0.0		
0.9		14.1			5.9			2.1			1.6			1.1		
1.7	1.7	23.9	23.9	70171	9.4	9.4	178049	3.3	3.3	511955	2.7	2.7	617594	1.7	1.7	1014359
2.5	1.6	53.9	39.8	40951	27.0	21.1	77242	11.6	9.5	171463	9.4	7.8	208264	6.4	5.3	306219
3.3	1.6	76.0	52.1	31281	41.6	32.2	50599	20.0	16.8	97178	17.1	14.4	113222	12.1	10.4	156158
4.1	1.6	96.6	42.7	38185	53.2	26.2	62197	25.8	14.2	114719	22.3	12.8	127001	15.4	9.0	180246
4.9	1.6	115.1	39.1	41688	62.1	20.4	79700	29.8	9.7	167356	25.4	8.3	196346	17.5	5.4	301286
5.8	1.6	137.3	40.8	39991	72.7	19.5	83448	33.7	7.9	207544	28.2	6.0	272746	19.0	3.6	456761
6.6	1.6	164.3	49.2	33119	81.1	19.0	85849	35.7	5.9	275504	29.6	4.2	390011	19.5	2.0	799245

* Tangent Shaft Stiffness Calculation; AE = Δ Load / Δ μ Strain

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, <u>NO SAND</u> 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, <u>NO SAND</u> 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