REPORT ON DRILLED SHAFT LOAD TESTING (OSTERBERG METHOD)

TS-1 - US 52 over ICE & Mill Creek
Jackson Co., IA (LT-9466)

Prepared for: **Longfellow Drilling**
1260 County Highway J23
Clearfield, IA 50840

Attention: **Mr. Mike Kemery**

PROJECT NUMBER: LT-9466, November 25, 2008

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

November 25, 2008

Longfellow Drilling
1260 County Highway J23
Clearfield, IA 50840

Attention: Mr. Mike Kemery

Load Test Report: TS-1 - US 52 over ICE & Mill Creek
Location: Jackson Co., IA (LT-9466)

Dear Mr. Kemery,

The enclosed report contains the data and analysis summary for the O-cell test performed on TS-1 - US 52 over ICE & Mill Creek on November 18, 2008. For your convenience, we have included an executive summary of the test results in addition to our standard detailed data report. Preliminary results were issued on November 21, 2008.

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,

FOR William G. Ryan, B.S.C.M.
Regional Manager, LOADTEST, Inc.

EXECUTIVE SUMMARY

On November 18, 2008, we tested a nominal 36-inch (914-mm) diameter dedicated test shaft constructed by Longfellow Drilling. Mr. Michael D. Ahrens and Mr. Andy Skiffington of LOADTEST, Inc. carried out the test. Longfellow Drilling constructed the 26.3-foot (8.01-meter) deep shaft under polymer slurry on November 5, 2008. Sub-surface conditions at the test shaft location consist primarily of lean to fat clay overburden underlain by moderately weathered to fresh dolomitic rock. Representatives of Iowa Department of Transportation and others observed construction and testing of the shaft.

The maximum sustained bi-directional load applied to the shaft was 4,853 kips (21.59 MN). At the maximum load, the displacements above and below the O-cell were 2.544 inches (64.62 mm) and 0.185 inches (4.71 mm), respectively. The average net unit shear in the rock above the O-cell is calculated to be 51.0 ksf (2443 kPa). The maximum applied end bearing pressure is calculated to be 594 ksf (28,420 kPa). Unit capacity values correspond to 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 6,432 kips (28.6 MN), the adjusted test data indicate this shaft would settle approximately 0.25 inches (6.4 mm) of which 0.13 inches (3.2 mm) 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 lean to fat clay overburden underlain by moderately weathered to fresh dolomitic rock. The generalized subsurface profile is included in Figure A and a boring log indicating conditions near the shaft is presented in Appendix E. More detailed geologic information can be obtained from Iowa Department of Transportation.

Test Shaft Construction: Longfellow Drilling began and completed construction of the dedicated test shaft on November 5, 2008. We understand that the nominal 36-inch (914-mm) test shaft (estimated to be 37 inches diameter based on core barrel dimensions) was excavated to a tip elevation of +573.0 feet (+174.65 meters) under polymer slurry utilizing a 42-inch (1,067-mm) O.D. temporary surface casing. A core barrel was used for drilling the rock socket which was then cleaned with a bucket and air-lift. After placing a seating layer of concrete in the base of the shaft with a pump line, the reinforcing cage with attached O-cell assembly was inserted into the excavation and allowed to come to rest on the freshly placed concrete. The pump line was then reinserted and the remainder of the concrete was placed. No unusual problems occurred during construction of the shaft. Representatives of Iowa Department of Transportation observed construction of the shaft.

OSTERBERG CELL TESTING

Shaft Instrumentation: Test shaft instrumentation and assembly was carried out under the direction of Mr. Michael D. Ahrens and Mr. Andy Skiffington of LOADTEST, Inc. between November 4, 2008 and November 5, 2008. The loading assembly consisted of one 34-inch (870-mm) O-cell located 1.7 feet (0.53 meters) above the tip of shaft. Calibrations of the O-cell and instrumentation used for this test are included in Appendix B.

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 (nominal ½-inch steel pipe) were attached to the reinforcing cage, diametrically opposed, extending from the top of the O-cell assembly to beyond the top of concrete. Compression of the shaft in the rock socket was measured by one section of Embedded Compression Telltales (ECT), consisting of telltale rods in nominal ½-inch steel pipe casings with an LVWDT attached (Appendix A, Page 3). Two additional lengths of steel pipe were also installed, extending from the top of the shaft to base of the O-cell to vent the break in the shaft formed by the expansion of the O-cell.

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

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 the ECTs. The full length telltale casings (described under Shaft Instrumentation) were not used. Two automated digital survey levels (Leica NA 3000 Series) were used to monitor the top of shaft movement from a distance of approximately 29 feet (8.8 meters) (Appendix A, Page 1).

A Bourdon pressure gage and electronic pressure transducers were used to measure the pressure applied to the O-cell at each load interval. We used the transducers for automatically setting and maintaining loads and for data analysis and real time plotting. The Bourdon gage was used as a check on the transducers. There was close agreement between the Bourdon gage and the pressure transducers.

Data Acquisition: All instrumentation were connected through a data logger (Data Electronics - DT500/600 Series Geologger) to a laptop computer allowing data to be recorded and stored automatically at 30-second intervals and displayed in real time. The same laptop computer synchronized to the data logging system was used to acquire the Leica NA3000 data sets.

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 load of 1,938 kips (8.6 MN) to the O-cell.

The Osterberg cell load test was conducted as follows: We pressurized the 34-inch (870-mm) diameter O-cell, with its base located 1.7 feet (0.53 meters) 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 loaded the shaft in 8 loading increments to a bi-directional gross O-cell load of 4,853 kips (21.59 MN). The loading was halted after load interval 1L-8 because the shaft above the O-cell had displaced significantly and was approaching ultimate capacity. The shaft was then unloaded in five 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 eight minutes by manually adjusting the O-cell pressure. The data logger automatically recorded the instrument readings every 30 seconds, but herein we report only the 1, 2, 4 and 8-minute readings (where applicable) 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 8 kips (0.04 MN) above the O-cell.

For the purposes of analyses herein, we use the 8-minute hold at increment 1L-8. This increment was maintained for a total of 16 minutes at which point the displacements above and below the O-cell were 2.625 inches (66.68 mm) and 0.189 inches (4.80 mm), respectively.

Upper Side Shear Resistance: The maximum upward applied *net load* to the upper side shear was 4,845 kips (21.55 MN) which occurred at load interval 1L-8. At this loading, the upward movement of the O-cell top was 2.544 inches (64.62 mm) and the average net unit side shear is calculated to be 51.0 ksf (2443 kPa).

In order to assess the side shear resistance of the test shaft, loads are calculated based on the strain gage data (Appendix A, Page 4) and an estimate of shaft stiffness (AE) which is presented below. 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 5,860 psi (40.40 MPa) on the day of the test. This, combined with the area of reinforcing steel and estimated shaft diameter, yields an average shaft stiffness (AE) of 4,940,000 kips (22,000 MN). Net unit shear curves are presented in Figure 3. 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	Displacement[1]	Net Unit Side Shear[2]
Average Rock Socket	**↑ 2.515"**	**51.0 ksf (2443 kPa)**
Strain Gage Level 3 to Top of Concrete	↑ 2.489"	41.3 ksf (1978 kPa)
Strain Gage Level 2 to Strain Gage Level 3	↑ 2.497"	99.9 ksf (4781 kPa)
Strain Gage Level 1 to Strain Gage Level 2	↑ 2.511"	65.1 ksf (3116 kPa)
Top of O-cell to Strain Gage Level 1	↑ 2.532"	23.2 ksf (1109 kPa)

[1] Average displacement of load transfer zone. [2] 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 Figure 3 for mobilized net unit shear vs. average shear zone 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 4,853 kips (21.59 MN) 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 0.185 inches (4.71 mm). The load taken in shear by the 1.7 feet (0.53 meters) of shaft section below the O-cell is calculated to be 421 kips (1.87 MN) using an interpolated average unit side shear value of 25.2 ksf (1207 kPa) and a 37-inch (940-mm) shaft diameter. The applied load to end bearing is then 4,432 kips (19.71 MN) and the unit end bearing at the base of the shaft is calculated to be 594 ksf (28,420 kPa) at the above noted displacement. A unit end bearing curve is presented in Figure 4.

Equivalent Top Load: Figure 5 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. 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.

A total shaft resistance of 9,698 kips (43.1 MN) was mobilized during the test. For an equivalent top loading of 6,432 kips (28.6 MN), the adjusted test data indicate this shaft would settle approximately 0.25 inches (6.4 mm) of which 0.13 inches (3.2 mm) is estimated elastic compression.

Note that, as explained previously, the equivalent top load curve applies to incremental loading durations of eight minutes. Creep effects will reduce the ultimate resistance of both components and increase 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.

Creep Limit: See Appendix D for our O-cell method for determining creep limit. The combined end bearing and lower side shear creep data (Appendix A, Page 3) indicate that no apparent creep limit was reached at a downward displacement of 0.19 inches (4.7 mm) (Appendix D, Figure 1). The upper side shear creep data (Appendix A, Page 3) indicate that a creep limit of 3,750 kips (16.7 MN) was reached at an upward displacement of 0.82 inches (20.7 mm) (Appendix D, Figure 2). The creep limit for a top-loaded shaft will not be reached until both shaft components reach their respective creep limits. The engineer should come to his own conclusions with regard to the suitability of the creep limit analysis to address long term creep which may be an important design consideration.

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, M.Eng, P.E.
Geotechnical Engineer

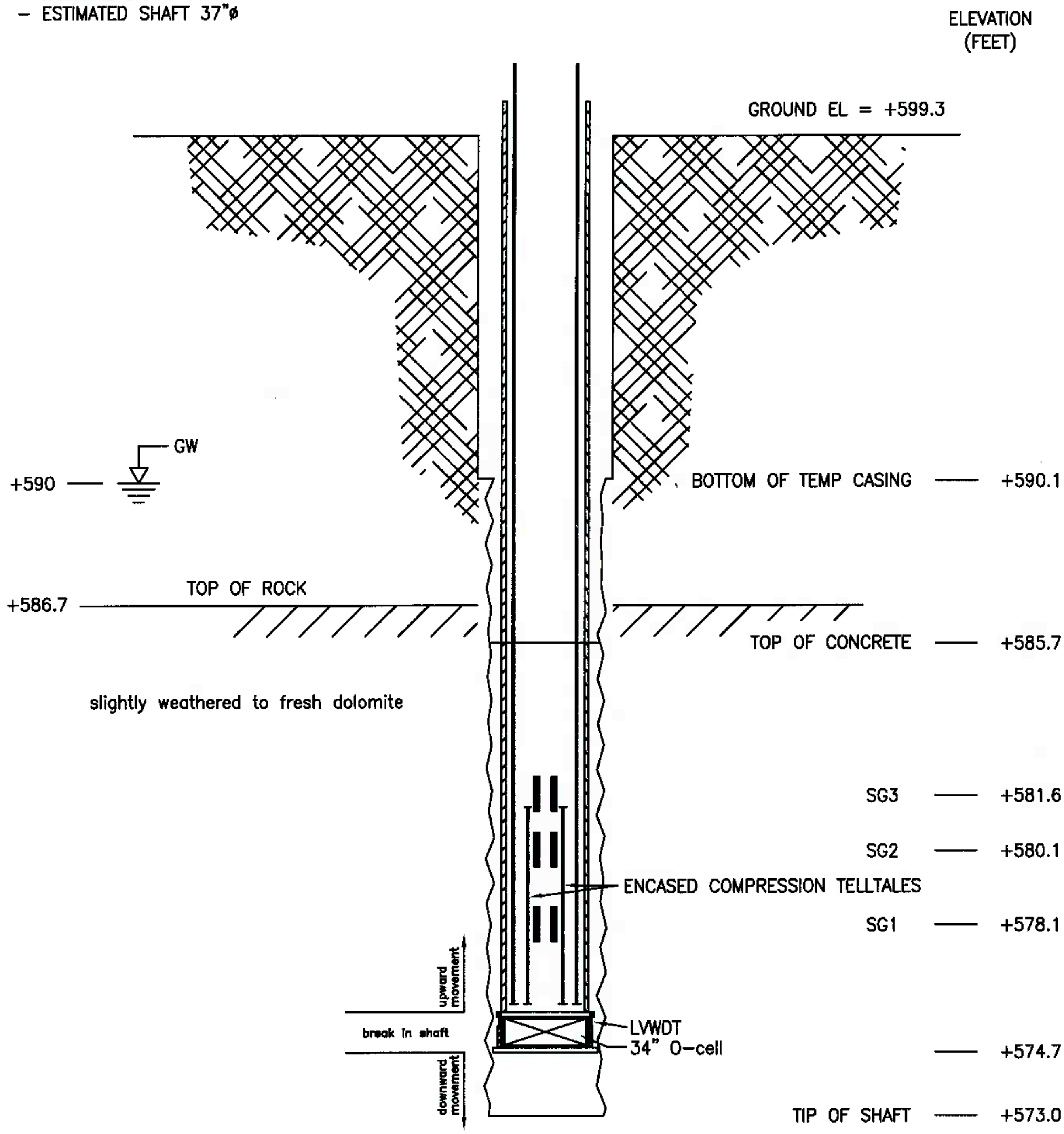
Reviewed for LOADTEST, Inc. by

David J. Jakstis, P.E.
Geotechnical Engineer

TABLE B:
SUMMARY OF DIMENSIONS, ELEVATIONS & SHAFT PROPERTIES

Shaft:			
Estimated shaft diameter (EL +585.7 ft to +573.0 ft)	=	37 in	940 mm
O-cell: 34-6-00048	=	34 in	860 mm
Bouyant weight of pile above base of O-cell	=	8.1 kips	0.036 MN
Estimated shaft stiffness, AE (EL +585.7 ft to +573.0 ft)	=	4,940,000 kips	22,000 MN
Elevation of ground surface	=	+599.3 ft	+182.66 m
Elevation of water table	=	+590.0 ft	+179.83 m
Elevation of top of shaft concrete (measured on test day)	=	+585.7 ft	+178.52 m
Elevation of top of O-cell (Assumed elevation of upward applied load.)	=	+575.9 ft	+175.53 m
Elevation of base of O-cell (Elevation of downward applied load.)	=	+574.7 ft	+175.18 m
Elevation of shaft tip	=	+573.0 ft	+174.65 m
Casings:			
Elevation of top of inner temporary casing (42.0 in O.D.)	=	+600.1 ft	+182.91 m
Elevation of bottom of inner temporary casing (42.0 in O.D.)	=	+590.1 ft	+179.86 m
Compression Sections:			
Elevation of top of ECTs	=	+581.3 ft	+177.17 m
Elevation of bottom of ECTs	=	+575.9 ft	+175.53 m
Strain Gages:			
Elevation of strain gage Level 3	=	+581.6 ft	+177.27 m
Elevation of strain gage Level 2	=	+580.1 ft	+176.81 m
Elevation of strain gage Level 1	=	+578.1 ft	+176.20 m
Miscellaneous:			
Top plate diameter (1-inch thickness)	=	34.25 in	870 mm
ReBar size (8 No.)	=	# 10	M 32
Spiral size (12 inch spacing)	=	# 5	M 16
ReBar cage diameter	=	30 in	762 mm
Unconfined compressive concrete strength	=	5860 psi	40.4 MPa
O-cell LVWDTs @ 0°, 180° and 270° with radius	=	17.5 in	445 mm

NOTE:
- NOMINAL TEMP CASING 42" OD
- NOMINAL SHAFT 36"ø
- ESTIMATED SHAFT 37"ø



GENERALIZED SOIL PROFILE
BASED ON BORING TB1

LOADTEST
2631-D NW 41st St.
Gainesville, FL 32606
Phone 800-368-1138
FAX 352-378-3934

SCHEMATIC SECTION OF TEST SHAFT
US 52 over Ice & Mill Creek – Jackson County, IA

DRAWN BY: JAG	DATE: 5/17/06	CHECKED BY:	LT-9466
REVISED BY: MDA	DATE: 11/24/08	SCALE: NTS	FIGURE A

Osterberg Cell Load-Displacement

TS-1 - US 52 over ICE Mill Creek - Jackson Co., IA

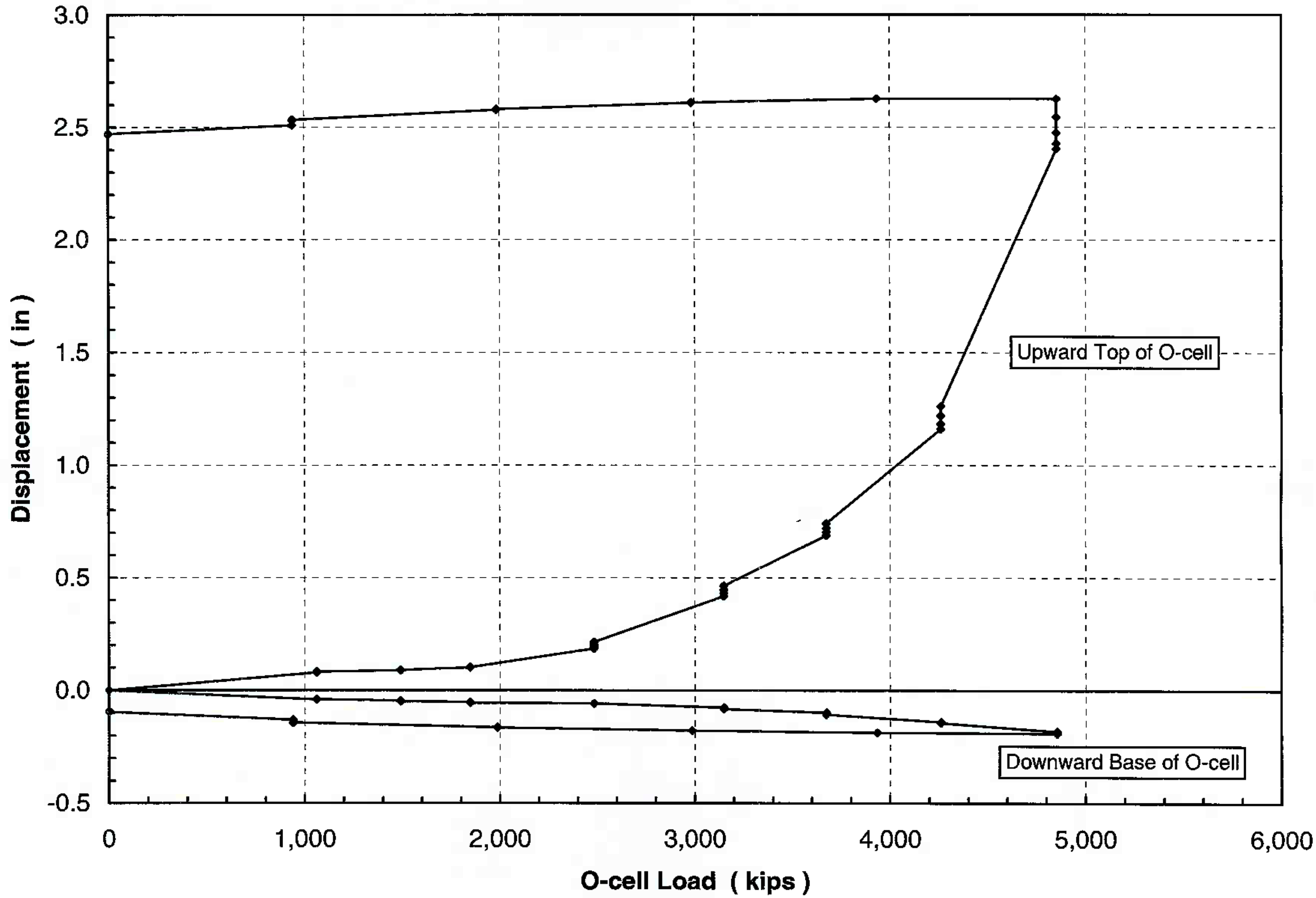
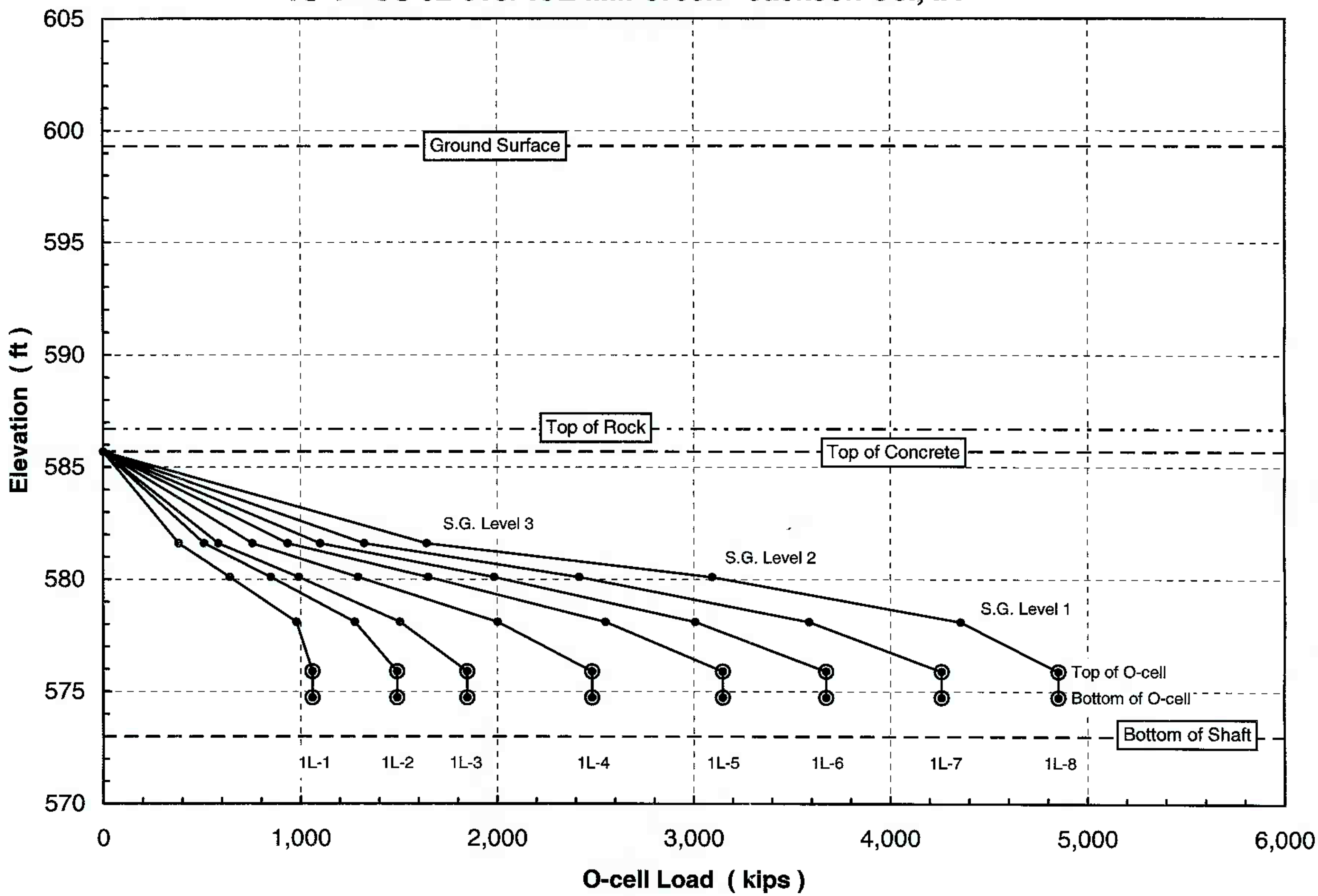


Figure 1 of 5

Strain Gage Load Distribution

TS-1 - US 52 over ICE Mill Creek - Jackson Co., IA



Mobilized Net Unit Side Shear

TS-1 - US 52 over ICE Mill Creek - Jackson Co., IA

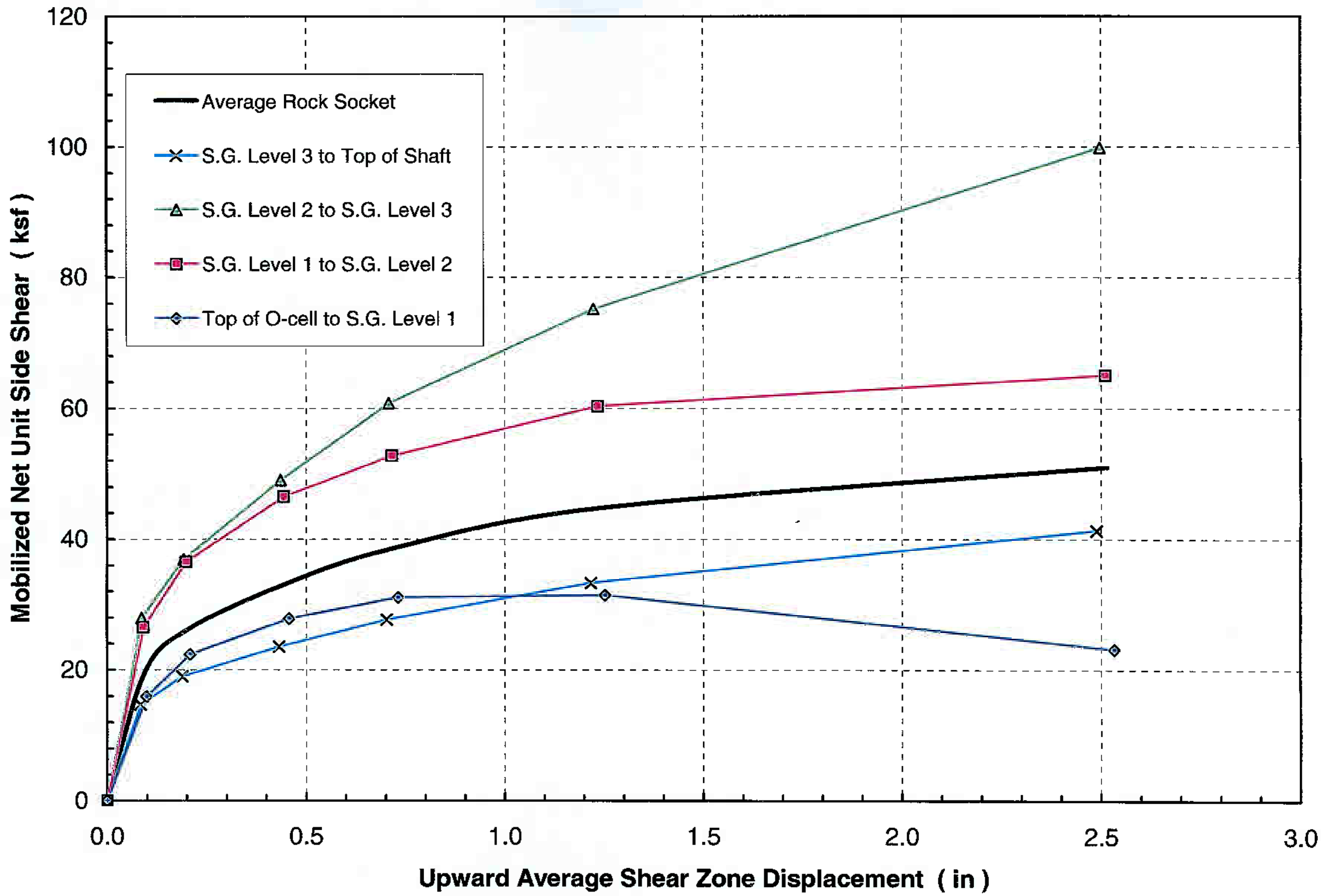
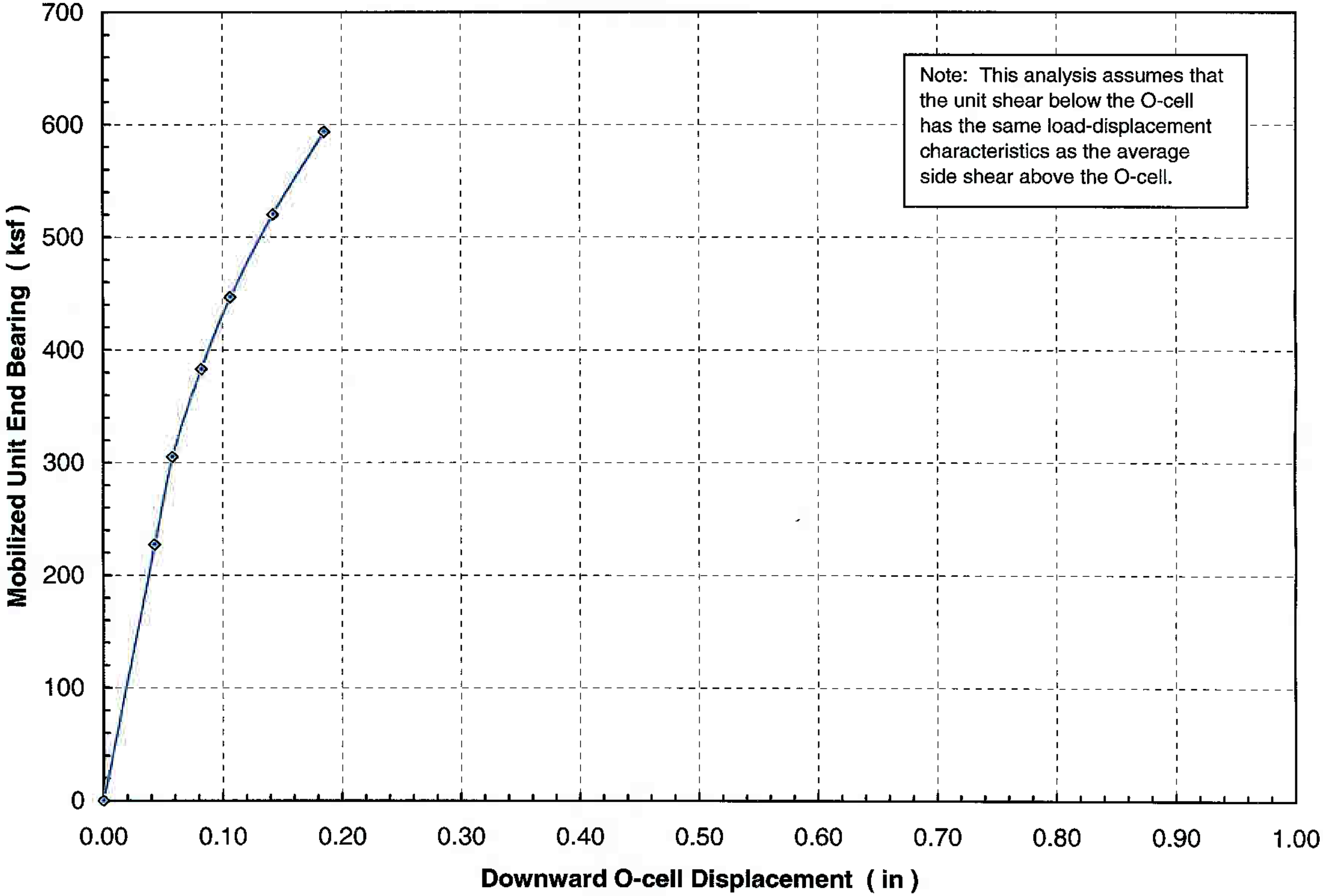


Figure 3 of 5

LOADTEST

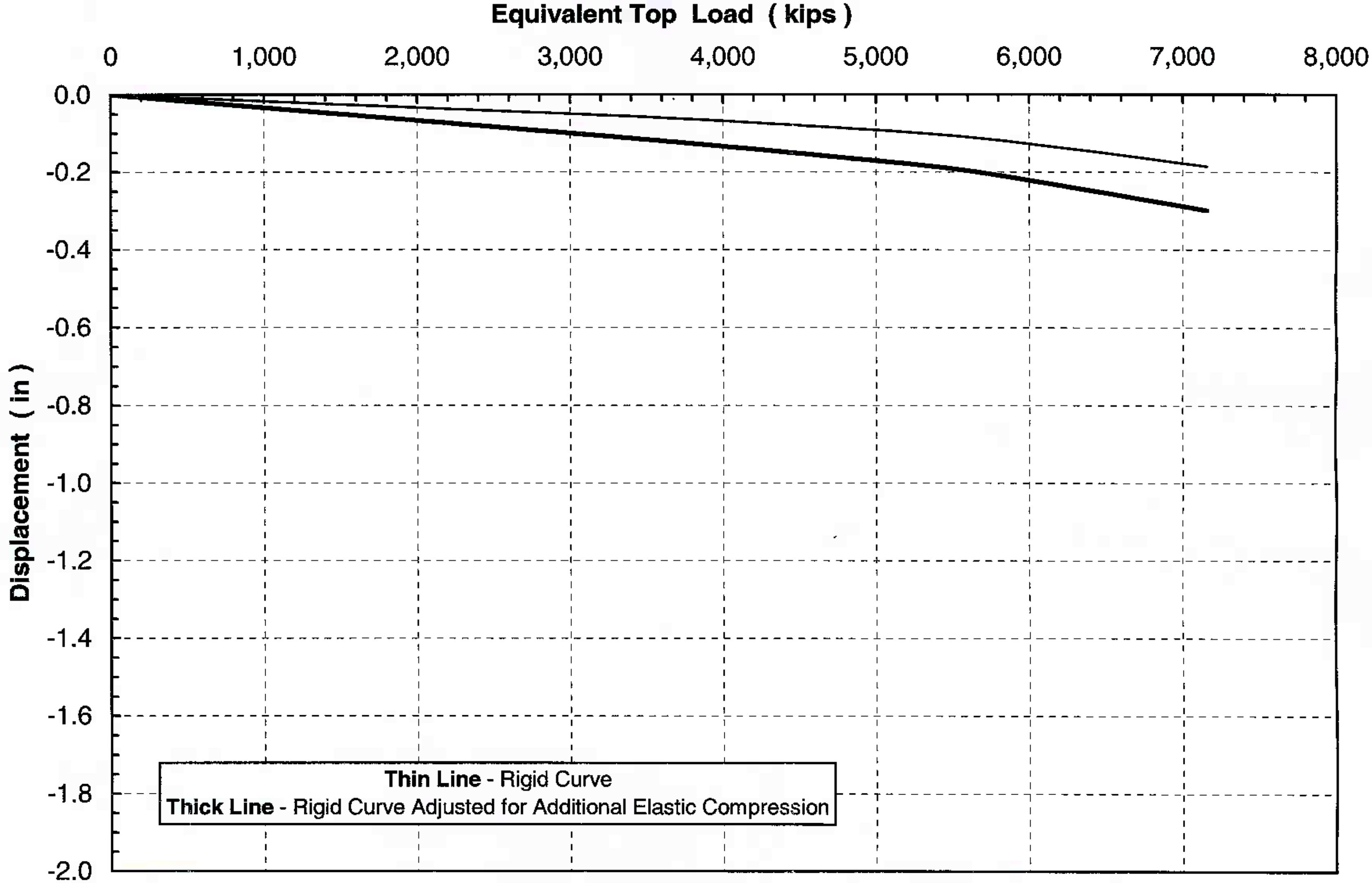
Mobilized Unit End Bearing

TS-1 - US 52 over ICE Mill Creek - Jackson Co., IA



Equivalent Top Load-Displacement

TS-1 - US 52 over ICE Mill Creek - Jackson Co., IA



APPENDIX A

FIELD DATA & DATA REDUCTION

LOADTEST

Upward Top of Shaft Movement and Shaft Compression
TS-1 - US 52 over ICE & Mill Creek - Jackson Co., IA

Load Test Increment	Hold Time (minutes)	Time (h:m:s)	O-cell Pressure (psi)	O-cell Load (kips)	Top of Shaft A (in)	Top of Shaft B (in)	Top of Shaft Average (in)	ECTs A - 20341 (in)	ECTs B - 20342 (in)	ECTs Average (in)
1 L - 0	-	11:01:30	0	0	0.000	0.000	0.000	0.000	0.000	0.000
1 L - 1	1	11:20:30	1,750	1,061	0.066	0.067	0.066	0.017	0.010	0.014
1 L - 1	2	11:21:30	1,750	1,061	0.068	0.065	0.067	0.017	0.010	0.014
1 L - 1	4	11:23:30	1,750	1,061	0.069	0.066	0.067	0.018	0.010	0.014
1 L - 1	8	11:27:30	1,750	1,061	0.071	0.066	0.069	0.018	0.010	0.014
1 L - 2	1	11:29:00	2,460	1,491	0.073	0.070	0.072	0.022	0.014	0.018
1 L - 2	2	11:30:00	2,460	1,491	0.074	0.068	0.071	0.022	0.014	0.018
1 L - 2	4	11:32:00	2,460	1,491	0.076	0.068	0.072	0.022	0.014	0.018
1 L - 2	8	11:36:00	2,460	1,491	0.075	0.069	0.072	0.022	0.014	0.018
1 L - 3	1	11:50:00	3,050	1,847	0.085	0.075	0.080	0.025	0.017	0.021
1 L - 3	2	11:51:00	3,050	1,847	0.086	0.074	0.080	0.026	0.017	0.021
1 L - 3	4	11:53:00	3,050	1,847	0.089	0.076	0.083	0.026	0.017	0.021
1 L - 3	8	11:57:00	3,050	1,847	0.087	0.077	0.082	0.026	0.017	0.021
1 L - 4	1	12:00:00	4,100	2,482	0.164	0.152	0.158	0.034	0.021	0.027
1 L - 4	2	12:01:00	4,100	2,482	0.173	0.160	0.167	0.034	0.021	0.027
1 L - 4	4	12:03:00	4,100	2,482	0.182	0.169	0.175	0.034	0.021	0.028
1 L - 4	8	12:07:00	4,100	2,482	0.194	0.178	0.186	0.035	0.021	0.028
1 L - 5	1	12:11:00	5,200	3,148	0.388	0.379	0.384	0.045	0.024	0.035
1 L - 5	2	12:12:00	5,200	3,148	0.397	0.394	0.396	0.046	0.024	0.035
1 L - 5	4	12:14:00	5,200	3,148	0.416	0.407	0.412	0.046	0.024	0.035
1 L - 5	8	12:18:00	5,200	3,148	0.433	0.424	0.428	0.047	0.025	0.036
1 L - 6	1	12:21:30	6,070	3,674	0.650	0.642	0.646	0.056	0.027	0.041
1 L - 6	2	12:22:30	6,070	3,674	0.666	0.657	0.662	0.056	0.027	0.042
1 L - 6	4	12:24:30	6,070	3,674	0.680	0.676	0.678	0.057	0.027	0.042
1 L - 6	8	12:28:30	6,070	3,674	0.700	0.696	0.698	0.058	0.027	0.043
1 L - 7	1	12:36:30	7,040	4,260	1.112	1.107	1.110	0.071	0.030	0.051
1 L - 7	2	12:37:30	7,040	4,260	1.136	1.131	1.133	0.072	0.031	0.051
1 L - 7	4	12:39:30	7,040	4,260	1.172	1.167	1.169	0.073	0.031	0.052
1 L - 7	8	12:43:30	7,040	4,260	1.214	1.206	1.210	0.074	0.031	0.052
1 L - 8	1	13:02:00	8,020	4,853	2.342	2.333	2.337	0.102	0.033	0.067
1 L - 8	2	13:03:00	8,020	4,853	2.364	2.356	2.360	0.102	0.033	0.067
1 L - 8	4	13:05:00	8,020	4,853	2.410	2.402	2.406	0.104	0.033	0.068
1 L - 8	8	13:09:00	8,020	4,853	2.480	2.470	2.475	0.106	0.033	0.069
1 L - 8	16	13:17:00	8,020	4,853	2.559	2.550	2.555	0.108	0.033	0.071
1 U - 1	1	13:21:00	6,500	3,934	2.564	2.556	2.560	0.106	0.028	0.067
1 U - 1	2	13:22:00	6,500	3,934	2.565	2.555	2.560	0.106	0.027	0.067
1 U - 1	4	13:24:00	6,500	3,934	2.564	2.555	2.560	0.106	0.027	0.067
1 U - 2	1	13:26:30	4,930	2,984	2.555	2.546	2.551	0.099	0.019	0.059
1 U - 2	2	13:27:30	4,930	2,984	2.554	2.546	2.550	0.099	0.019	0.059
1 U - 2	4	13:29:30	4,930	2,984	2.554	2.545	2.549	0.099	0.019	0.059
1 U - 3	1	13:32:00	3,280	1,986	2.536	2.528	2.532	0.088	0.009	0.049
1 U - 3	2	13:33:00	3,280	1,986	2.534	2.526	2.530	0.088	0.009	0.048
1 U - 3	4	13:35:00	3,280	1,986	2.534	2.524	2.529	0.087	0.009	0.048
1 U - 4	1	13:39:30	1,550	940	2.501	2.493	2.497	0.073	0.000	0.036
1 U - 4	2	13:40:30	1,550	940	2.499	2.491	2.495	0.072	0.000	0.036
1 U - 4	4	13:42:30	1,550	940	2.487	2.479	2.483	0.060	-0.007	0.027
1 U - 5	1	13:47:30	0	0	2.459	2.450	2.455	0.044	-0.009	0.017
1 U - 5	2	13:48:30	0	0	2.458	2.450	2.454	0.044	-0.009	0.017
1 U - 5	4	13:50:30	0	0	2.456	2.449	2.452	0.043	-0.009	0.017
1 U - 5	8	13:54:30	0	0	2.455	2.447	2.451	0.043	-0.009	0.017

LOADTEST

O-cell Expansion
TS-1 - US 52 over ICE & Mill Creek - Jackson Co., IA

Load Test Increment	Hold Time (minutes)	Time (h:m:s)	O-cell Pressure (psi)	O-cell Load (kips)	O-cell Expansion A - 19360 (in)	B - 19361 (in)	C - 19362 * (in)	Average (in)
1 L - 0	-	11:01:30	0	0	0.000	0.000	0.000	0.000
1 L - 1	1	11:20:30	1,750	1,061	0.104	0.135	0.163	0.120
1 L - 1	2	11:21:30	1,750	1,061	0.105	0.136	0.165	0.120
1 L - 1	4	11:23:30	1,750	1,061	0.105	0.137	0.166	0.121
1 L - 1	8	11:27:30	1,750	1,061	0.106	0.138	0.167	0.122
1 L - 2	1	11:29:00	2,460	1,491	0.118	0.152	0.183	0.135
1 L - 2	2	11:30:00	2,460	1,491	0.119	0.153	0.184	0.136
1 L - 2	4	11:32:00	2,460	1,491	0.120	0.154	0.185	0.137
1 L - 2	8	11:36:00	2,460	1,491	0.120	0.155	0.186	0.138
1 L - 3	1	11:50:00	3,050	1,847	0.134	0.171	0.202	0.153
1 L - 3	2	11:51:00	3,050	1,847	0.136	0.173	0.204	0.154
1 L - 3	4	11:53:00	3,050	1,847	0.137	0.174	0.205	0.156
1 L - 3	8	11:57:00	3,050	1,847	0.139	0.175	0.206	0.157
1 L - 4	1	12:00:00	4,100	2,482	0.233	0.253	0.257	0.243
1 L - 4	2	12:01:00	4,100	2,482	0.242	0.262	0.260	0.252
1 L - 4	4	12:03:00	4,100	2,482	0.251	0.271	0.264	0.261
1 L - 4	8	12:07:00	4,100	2,482	0.262	0.282	0.269	0.272
1 L - 5	1	12:11:00	5,200	3,148	0.482	0.505	0.381	0.494
1 L - 5	2	12:12:00	5,200	3,148	0.499	0.523	0.391	0.511
1 L - 5	4	12:14:00	5,200	3,148	0.516	0.541	0.402	0.529
1 L - 5	8	12:18:00	5,200	3,148	0.533	0.559	0.421	0.546
1 L - 6	1	12:21:30	6,070	3,674	0.766	0.805	0.675	0.785
1 L - 6	2	12:22:30	6,070	3,674	0.782	0.824	0.696	0.803
1 L - 6	4	12:24:30	6,070	3,674	0.802	0.846	0.720	0.824
1 L - 6	8	12:28:30	6,070	3,674	0.823	0.870	0.744	0.847
1 L - 7	1	12:36:30	7,040	4,260	1.259	1.339	1.216	1.299
1 L - 7	2	12:37:30	7,040	4,260	1.283	1.365	1.242	1.324
1 L - 7	4	12:39:30	7,040	4,260	1.319	1.403	1.279	1.361
1 L - 7	8	12:43:30	7,040	4,260	1.361	1.449	1.327	1.405
1 L - 8	1	13:02:00	8,020	4,853	2.518	2.651	2.565	2.584
1 L - 8	2	13:03:00	8,020	4,853	2.542	2.676	2.593	2.609
1 L - 8	4	13:05:00	8,020	4,853	2.589	2.726	2.642	2.658
1 L - 8	8	13:09:00	8,020	4,853	2.659	2.800	2.723	2.730
1 L - 8	16	13:17:00	8,020	4,853	2.742	2.887	2.811	2.814
1 U - 1	1	13:21:00	6,500	3,934	2.739	2.886	2.814	2.812
1 U - 1	2	13:22:00	6,500	3,934	2.739	2.885	2.814	2.812
1 U - 1	4	13:24:00	6,500	3,934	2.739	2.885	2.814	2.812
1 U - 2	1	13:26:30	4,930	2,984	2.714	2.859	2.788	2.786
1 U - 2	2	13:27:30	4,930	2,984	2.713	2.858	2.788	2.786
1 U - 2	4	13:29:30	4,930	2,984	2.713	2.858	2.787	2.785
1 U - 3	1	13:32:00	3,280	1,986	2.673	2.815	2.738	2.744
1 U - 3	2	13:33:00	3,280	1,986	2.671	2.813	2.737	2.742
1 U - 3	4	13:35:00	3,280	1,986	2.669	2.810	2.733	2.740
1 U - 4	1	13:39:30	1,550	940	2.607	2.743	2.656	2.675
1 U - 4	2	13:40:30	1,550	940	2.607	2.742	2.655	2.674
1 U - 4	4	13:42:30	1,550	940	2.574	2.703	2.611	2.638
1 U - 5	1	13:47:30	0	0	2.515	2.620	2.497	2.567
1 U - 5	2	13:48:30	0	0	2.514	2.617	2.494	2.565
1 U - 5	4	13:50:30	0	0	2.511	2.614	2.490	2.563
1 U - 5	8	13:54:30	0	0	2.509	2.611	2.485	2.560

* LVWDT C is not included in the average due to its orientation.
LVWDTs A and B are oriented 180° opposed.

Upward and Downward O-cell Plate Movement and Creep (calculated)
TS-1 - US 52 over ICE & Mill Creek - Jackson Co., IA

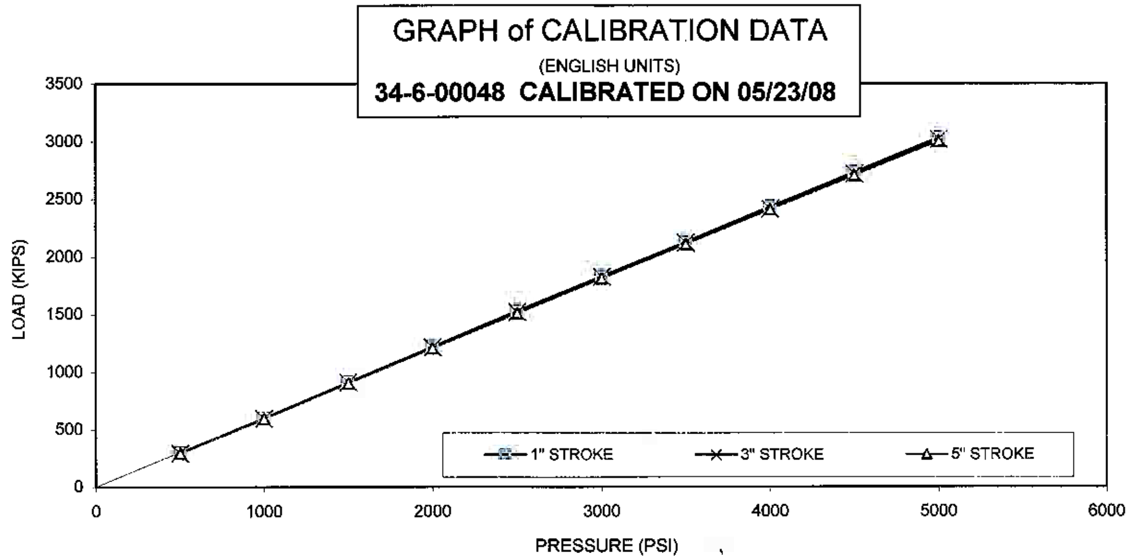
Load Test Increment	Hold Time (minutes)	Time (h:m:s)	O-cell		Top of Shaft (in)	Elastic Comp. (in)	Top Plate Movement (in)	O-cell Expansion (in)	Bot. Plate Movement (in)	Creep Up Per Hold (in)	Creep Dn Per Hold (in)
			Pressure (psi)	Load (kips)							
1 L - 0	-	11:01:30	0	0	0.000	0.000	0.000	0.000	0.000		
1 L - 1	1	11:20:30	1,750	1,061	0.066	0.014	0.080	0.120	-0.040		
1 L - 1	2	11:21:30	1,750	1,061	0.067	0.014	0.080	0.120	-0.040	0.001	0.000
1 L - 1	4	11:23:30	1,750	1,061	0.067	0.014	0.081	0.121	-0.040	0.001	0.000
1 L - 1	8	11:27:30	1,750	1,061	0.069	0.014	0.082	0.122	-0.039	0.001	-0.001
1 L - 2	1	11:29:00	2,460	1,491	0.072	0.018	0.089	0.135	-0.046		
1 L - 2	2	11:30:00	2,460	1,491	0.071	0.018	0.088	0.136	-0.047	-0.001	0.001
1 L - 2	4	11:32:00	2,460	1,491	0.072	0.018	0.090	0.137	-0.047	0.002	-0.001
1 L - 2	8	11:36:00	2,460	1,491	0.072	0.018	0.090	0.138	-0.048	0.000	0.001
1 L - 3	1	11:50:00	3,050	1,847	0.080	0.021	0.101	0.153	-0.052		
1 L - 3	2	11:51:00	3,050	1,847	0.080	0.021	0.101	0.154	-0.053	0.000	0.002
1 L - 3	4	11:53:00	3,050	1,847	0.083	0.021	0.104	0.156	-0.052	0.003	-0.001
1 L - 3	8	11:57:00	3,050	1,847	0.082	0.021	0.103	0.157	-0.054	-0.001	0.002
1 L - 4	1	12:00:00	4,100	2,482	0.158	0.027	0.185	0.243	-0.058		
1 L - 4	2	12:01:00	4,100	2,482	0.167	0.027	0.194	0.252	-0.058	0.009	0.000
1 L - 4	4	12:03:00	4,100	2,482	0.175	0.028	0.203	0.261	-0.058	0.009	0.001
1 L - 4	8	12:07:00	4,100	2,482	0.186	0.028	0.214	0.272	-0.058	0.011	-0.001
1 L - 5	1	12:11:00	5,200	3,148	0.384	0.035	0.418	0.494	-0.076		
1 L - 5	2	12:12:00	5,200	3,148	0.396	0.035	0.431	0.511	-0.080	0.012	0.005
1 L - 5	4	12:14:00	5,200	3,148	0.412	0.035	0.447	0.529	-0.082	0.016	0.001
1 L - 5	8	12:18:00	5,200	3,148	0.428	0.036	0.464	0.546	-0.082	0.017	0.000
1 L - 6	1	12:21:30	6,070	3,674	0.646	0.041	0.687	0.785	-0.098		
1 L - 6	2	12:22:30	6,070	3,674	0.662	0.042	0.703	0.803	-0.100	0.016	0.001
1 L - 6	4	12:24:30	6,070	3,674	0.678	0.042	0.720	0.824	-0.104	0.017	0.005
1 L - 6	8	12:28:30	6,070	3,674	0.698	0.043	0.740	0.847	-0.107	0.020	0.002
1 L - 7	1	12:36:30	7,040	4,260	1.110	0.051	1.161	1.299	-0.139		
1 L - 7	2	12:37:30	7,040	4,260	1.133	0.051	1.184	1.324	-0.140	0.024	0.001
1 L - 7	4	12:39:30	7,040	4,260	1.169	0.052	1.221	1.361	-0.140	0.037	0.000
1 L - 7	8	12:43:30	7,040	4,260	1.210	0.052	1.262	1.405	-0.142	0.041	0.002
1 L - 8	1	13:02:00	8,020	4,853	2.337	0.067	2.404	2.584	-0.180		
1 L - 8	2	13:03:00	8,020	4,853	2.360	0.067	2.427	2.609	-0.182	0.023	0.001
1 L - 8	4	13:05:00	8,020	4,853	2.406	0.068	2.475	2.658	-0.183	0.047	0.002
1 L - 8	8	13:09:00	8,020	4,853	2.475	0.069	2.544	2.730	-0.185	0.070	0.002
1 L - 8	16	13:17:00	8,020	4,853	2.555	0.071	2.625	2.814	-0.189	0.081	0.004
1 U - 1	1	13:21:00	6,500	3,934	2.560	0.067	2.627	2.812	-0.186		
1 U - 1	2	13:22:00	6,500	3,934	2.560	0.067	2.627	2.812	-0.186		
1 U - 1	4	13:24:00	6,500	3,934	2.560	0.067	2.626	2.812	-0.186		
1 U - 2	1	13:26:30	4,930	2,984	2.551	0.059	2.609	2.786	-0.177		
1 U - 2	2	13:27:30	4,930	2,984	2.550	0.059	2.609	2.786	-0.177		
1 U - 2	4	13:29:30	4,930	2,984	2.549	0.059	2.608	2.785	-0.177		
1 U - 3	1	13:32:00	3,280	1,986	2.532	0.049	2.581	2.744	-0.163		
1 U - 3	2	13:33:00	3,280	1,986	2.530	0.048	2.578	2.742	-0.164		
1 U - 3	4	13:35:00	3,280	1,986	2.529	0.048	2.577	2.740	-0.162		
1 U - 4	1	13:39:30	1,550	940	2.497	0.036	2.533	2.675	-0.142		
1 U - 4	2	13:40:30	1,550	940	2.495	0.036	2.531	2.674	-0.143		
1 U - 4	4	13:42:30	1,550	940	2.483	0.027	2.509	2.638	-0.129		
1 U - 5	1	13:47:30	0	0	2.455	0.017	2.472	2.567	-0.096		
1 U - 5	2	13:48:30	0	0	2.454	0.017	2.471	2.565	-0.095		
1 U - 5	4	13:50:30	0	0	2.452	0.017	2.469	2.563	-0.093		
1 U - 5	8	13:54:30	0	0	2.451	0.017	2.468	2.560	-0.092		

Strain Gage Readings and Loads at Levels 1, 2 and 3
TS-1 - US 52 over ICE & Mill Creek - Jackson Co., IA

Load	Hold	Time	O-cell		Level 1			Level 2			Level 3		
Test Increment	Time (minutes)	(h:m:s)	Pressure (psi)	Load (kips)	A - 22530 (με)	B - 22531 (με)	Av. Load (kips)	A - 22532 (με)	B - 22533 (με)	Av. Load (kips)	A - 22534 (με)	B - 22535 (με)	Av. Load (kips)
1 L - 0	-	11:01:30	0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
1 L - 1	1	11:20:30	1,750	1,061	137.9	249.1	956	98.7	153.3	622	66.9	82.4	369
1 L - 1	2	11:21:30	1,750	1,061	140.2	252.3	969	100.6	155.6	633	68.4	83.8	376
1 L - 1	4	11:23:30	1,750	1,061	140.4	253.2	972	101.3	156.5	637	69.0	84.5	379
1 L - 1	8	11:27:30	1,750	1,061	141.4	254.9	979	102.2	157.7	642	69.7	85.4	383
1 L - 2	1	11:29:00	2,460	1,491	191.5	316.8	1255	140.9	196.0	832	93.2	108.3	498
1 L - 2	2	11:30:00	2,460	1,491	192.7	318.6	1263	142.2	197.4	839	94.2	109.3	503
1 L - 2	4	11:32:00	2,460	1,491	193.5	320.3	1269	143.4	198.8	845	95.2	110.1	507
1 L - 2	8	11:36:00	2,460	1,491	194.5	322.0	1276	144.6	200.0	851	96.1	111.0	512
1 L - 3	1	11:50:00	3,050	1,847	234.2	369.9	1492	171.1	226.5	982	109.4	123.8	576
1 L - 3	2	11:51:00	3,050	1,847	236.8	373.4	1507	172.8	228.4	991	110.3	124.8	581
1 L - 3	4	11:53:00	3,050	1,847	236.1	373.7	1506	172.5	228.7	991	110.3	125.1	581
1 L - 3	8	11:57:00	3,050	1,847	235.5	374.1	1506	172.3	229.0	991	110.7	126.0	585
1 L - 4	1	12:00:00	4,100	2,482	301.2	494.4	1965	213.2	301.6	1272	133.1	169.4	747
1 L - 4	2	12:01:00	4,100	2,482	301.0	498.8	1975	213.7	303.8	1278	133.0	170.6	750
1 L - 4	4	12:03:00	4,100	2,482	300.5	503.3	1985	214.1	305.6	1284	133.0	171.7	752
1 L - 4	8	12:07:00	4,100	2,482	301.2	509.6	2003	215.4	308.2	1293	133.3	173.0	757
1 L - 5	1	12:11:00	5,200	3,148	354.6	657.6	2500	264.0	390.6	1617	152.0	225.7	933
1 L - 5	2	12:12:00	5,200	3,148	353.9	665.2	2517	265.8	393.5	1628	151.2	227.4	935
1 L - 5	4	12:14:00	5,200	3,148	352.8	672.3	2532	267.4	395.9	1638	150.4	228.6	936
1 L - 5	8	12:18:00	5,200	3,148	352.4	680.4	2551	269.4	398.3	1649	149.5	229.5	936
1 L - 6	1	12:21:30	6,070	3,674	385.6	806.2	2944	321.6	465.7	1945	165.1	276.3	1090
1 L - 6	2	12:22:30	6,070	3,674	385.3	813.9	2962	323.7	468.4	1956	164.8	277.9	1093
1 L - 6	4	12:24:30	6,070	3,674	385.3	823.5	2986	326.9	471.2	1971	164.7	279.4	1097
1 L - 6	8	12:28:30	6,070	3,674	384.1	833.5	3008	329.6	473.9	1985	164.4	281.2	1101
1 L - 7	1	12:36:30	7,040	4,260	431.7	993.4	3520	408.7	549.6	2367	183.5	345.2	1306
1 L - 7	2	12:37:30	7,040	4,260	432.8	999.4	3537	412.2	551.8	2381	183.5	347.7	1312
1 L - 7	4	12:39:30	7,040	4,260	434.4	1007.8	3562	417.1	554.8	2400	183.3	351.0	1320
1 L - 7	8	12:43:30	7,040	4,260	435.4	1016.8	3587	421.8	556.9	2417	182.3	353.9	1324
1 L - 8	1	13:02:00	8,020	4,853	499.2	1236.0	4286	553.4	676.4	3038	194.8	461.9	1622
1 L - 8	2	13:03:00	8,020	4,853	501.0	1238.7	4297	555.8	677.5	3046	194.7	463.2	1625
1 L - 8	4	13:05:00	8,020	4,853	502.8	1246.4	4321	560.1	681.7	3067	194.8	466.5	1634
1 L - 8	8	13:09:00	8,020	4,853	506.4	1257.2	4356	566.7	686.0	3094	194.5	470.3	1642
1 L - 8	16	13:17:00	8,020	4,853	515.0	1274.6	4420	578.8	693.8	3143	195.9	476.1	1660
1 U - 1	1	13:21:00	6,500	3,934	430.6	1224.4	4088	520.9	660.0	2917	168.6	453.0	1535
1 U - 1	2	13:22:00	6,500	3,934	430.0	1223.7	4085	520.2	659.2	2913	167.9	452.3	1532
1 U - 1	4	13:24:00	6,500	3,934	429.0	1221.9	4078	518.7	657.6	2906	167.0	451.1	1527
1 U - 2	1	13:26:30	4,930	2,984	308.9	1117.9	3524	425.0	595.3	2520	123.6	412.0	1323
1 U - 2	2	13:27:30	4,930	2,984	309.1	1118.3	3526	424.8	595.2	2519	123.2	411.8	1321
1 U - 2	4	13:29:30	4,930	2,984	309.2	1118.6	3527	424.6	594.8	2518	123.0	411.6	1320
1 U - 3	1	13:32:00	3,280	1,986	154.8	958.9	2751	299.1	493.4	1958	62.8	348.9	1017
1 U - 3	2	13:33:00	3,280	1,986	151.3	957.8	2739	296.6	491.8	1947	61.4	348.1	1011
1 U - 3	4	13:35:00	3,280	1,986	149.7	954.4	2727	294.2	489.8	1936	60.2	347.1	1006
1 U - 4	1	13:39:30	1,550	940	-72.6	742.2	1654	157.6	345.7	1243	-8.5	258.2	617
1 U - 4	2	13:40:30	1,550	940	-69.1	745.0	1670	159.3	346.9	1250	-8.6	257.5	615
1 U - 4	4	13:42:30	1,550	940	-187.1	576.5	962	65.7	233.7	739	-55.7	183.0	314
1 U - 5	1	13:47:30	0	0	-192.9	366.7	429	-3.1	128.6	310	-85.7	125.2	98
1 U - 5	2	13:48:30	0	0	-192.4	363.0	421	-3.7	127.7	306	-85.2	125.0	98
1 U - 5	4	13:50:30	0	0	-191.3	357.9	412	-4.7	126.5	301	-84.0	124.7	100
1 U - 5	8	13:54:30	0	0	-190.0	351.6	399	-5.5	125.7	297	-84.6	125.0	100

APPENDIX B

O-CELL AND INSTRUMENTATION CALIBRATION SHEETS



STROKE:	1 INCH	3 INCH	5 INCH
PRESSURE PSI	LOAD KIPS	LOAD KIPS	LOAD KIPS
0	0	0	0
500	298	297	296
1000	603	600	600
1500	918	916	910
2000	1222	1217	1211
2500	1531	1522	1513
3000	1831	1827	1813
3500	2129	2123	2113
4000	2436	2421	2414
4500	2734	2721	2708
5000	3033	3013	3005

34" O-CELL, SERIAL # 34-6-00048

LOAD CONVERSION FORMULA

LOAD = PRESSURE * 0.6048 + (2.70)
{KIPS} {PSI}

Regression Output:

Constant	2.7016	kips
X Coefficient	0.6048	kip / psi
R Square	0.9999	
No. of Observations	30	
Degrees of Freedom	28	
Std Err of Y Est	9.47	
Std Err of X Coeff	0.0012	

CALIBRATION STANDARDS:

All data presented are 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 gages, ANSI specifications B40.1.

* AE & FC CUSTOMER: LOADTEST Inc	* CONTRACTOR.: LONGFELLOW DRILLING
* AE & FC JOB NO: SO4260	* JOB LOCATION: CLEARFIELD, IA
* CUSTOMER P.O. NO.: LT-9466	* DATED: 10/22/08

SERVICE ENGINEER: ______ DATE: 10-29-08

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

Vibrating Wire Displacement Transducer Calibration Report

Range: 150 mm

Serial Number: 08-19360

Calibration Date: August 26, 2008

Temperature: 24.4 °C

Calibration Instruction: CI-4400

Technician: Elice

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2563	2560	2562	-0.10	-0.07	0.08	0.06
30.0	3526	3520	3523	29.89	-0.07	29.86	-0.10
60.0	4493	4492	4493	60.13	0.09	59.99	-0.01
90.0	5457	5457	5457	90.22	0.15	90.07	0.05
120.0	6415	6414	6415	120.09	0.06	120.05	0.03
150.0	7366	7366	7366	149.77	-0.16	149.95	-0.03

(mm) Linear Gage Factor (G): 0.03119 (mm/ digit) **Regression Zero: 2565**

Polynomial Gage Factors: A: 5.90818E-08 B: 0.03061 C: -78.703

(inches) Linear Gage Factor (G): 0.001228 (inches/ digit)

Polynomial Gage Factors: A: 2.32606E-09 B: 0.001205 C: -3.0985

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

Function Test at Shipment:

GK-401 Pos. B : 5001

Temp(T_0): 25.4 °C

Date: October 28, 2008

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

Range: 150 mm

Serial Number: 08-19361

Calibration Date: August 26, 2008

Temperature: 24.4 °C

Calibration Instruction: CI-4400

Technician: Elice

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2627	2625	2626	-0.14	-0.09	0.06	0.04
30.0	3585	3585	3585	29.99	0.00	29.95	-0.03
60.0	4541	4540	4541	60.01	0.01	59.85	-0.10
90.0	5503	5502	5503	90.24	0.16	90.08	0.05
120.0	6455	6456	6456	120.18	0.12	120.15	0.10
150.0	7395	7395	7395	149.70	-0.20	149.90	-0.07

(mm) Linear Gage Factor (G): 0.03142 (mm/ digit) **Regression Zero: 2630**

Polynomial Gage Factors: A: 6.60885E-08 B: 0.03076 C: -81.160

(inches) Linear Gage Factor (G): 0.001237 (inches/ digit)

Polynomial Gage Factors: A: 2.60191E-09 B: 0.001211 C: -3.1953

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

Function Test at Shipment:

GK-401 Pos. B : 5041 Temp(T_0): 25.6 °C Date: October 28, 2008

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

Range: 150 mm

Serial Number: 08-19362

Calibration Date: August 26, 2008

Temperature: 24.4 °C

Calibration Instruction: CI-4400

Technician: Erica

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2577	2577	2577	-0.26	-0.18	0.00	0.00
30.0	3551	3549	3550	30.04	0.03	29.99	-0.01
60.0	4520	4519	4520	60.24	0.16	60.03	0.02
90.0	5481	5481	5481	90.19	0.13	89.98	-0.01
120.0	6440	6439	6440	120.04	0.03	119.99	0.00
150.0	7393	7393	7393	149.74	-0.17	150.01	0.00

(mm) Linear Gage Factor (G): 0.03115 (mm/ digit) **Regression Zero: 2585**

Polynomial Gage Factors: A: 8.48418E-08 B: 0.03030 C: -78.651

(inches) Linear Gage Factor (G): 0.001226 (inches/ digit)

Polynomial Gage Factors: A: 3.34023E-09 B: 0.001193 C: -3.0965

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

Function Test at Shipment:

GK-401 Pos. B : 5018 Temp(T_0): 25.9 °C Date: October 28, 2008

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

Range: 25 mm

Serial Number: 08-20341

Calibration Date: September 25, 2008

Temperature: 23.9 °C

Calibration Instruction: CI-4400

Technician: Erica

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2144	2141	2143	-0.06	-0.24	-0.01	-0.03
5.0	3320	3318	3319	5.02	0.09	5.01	0.05
10.0	4484	4479	4482	10.04	0.18	10.00	0.01
15.0	5638	5636	5637	15.04	0.14	14.99	-0.02
20.0	6788	6785	6787	20.00	0.00	19.99	-0.04
25.0	7934	7933	7934	24.96	-0.18	25.01	0.03

(mm) Linear Gage Factor (G): 0.004320 (mm/ digit) **Regression Zero: 2156**

Polynomial Gage Factors: A: 1.1486E-08 B: 0.004204 C: -9.0668

(inches) Linear Gage Factor (G): 0.0001701 (inches/ digit)

Polynomial Gage Factors: A: 4.52203E-10 B: 0.0001655 C: -0.35696

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

Function Test at Shipment:

GK-401 Pos. B : 4805 Temp(T_0): 25.3 °C Date: October 28, 2008

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

Range: 25 mm

Serial Number: 08-20342

Calibration Date: September 25, 2008

Temperature: 23.9 °C

Calibration Instruction: CI-4400

Technician: Elica

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2090	2089	2090	-0.06	-0.25	-0.01	-0.03
5.0	3250	3249	3250	5.02	0.09	5.01	0.05
10.0	4396	4394	4395	10.04	0.18	10.00	0.01
15.0	5534	5533	5534	15.04	0.14	14.99	-0.03
20.0	6668	6667	6668	20.01	0.02	20.00	-0.02
25.0	7796	7795	7796	24.95	-0.20	25.00	0.02

(mm) Linear Gage Factor (G): 0.004383 **(mm/ digit)** **Regression Zero:** 2103

Polynomial Gage Factors: **A:** 1.23953E-08 **B:** 0.004261 **C:** -8.9642

(inches) Linear Gage Factor (G): 0.0001726 **(inches/ digit)**

Polynomial Gage Factors: **A:** 4.88003E-10 **B:** 0.0001677 **C:** -0.35292

Calculated Displacement: **Linear,** $D = G(R_1 - R_0)$

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

Function Test at Shipment:

GK-401 Pos. B : 4576 Temp(T_0): 25.4 °C Date: October 28, 2008

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: 08-22530

Prestress: 35,000 psi

Temperature: 23.1 °C

Calibration Instruction: CI-VW Rebar

Date of Calibration: October 3, 2008

Cable Length: 36 ft.

Factory Zero Reading: 6882

Regression Zero: 6911

Technician: Erica

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6964	6961	6963		
1,500	7632	7632	7632	670	-0.13
3,000	8365	8361	8363	731	0.08
4,500	9088	9091	9090	727	0.14
6,000	9811	9808	9810	720	-0.03
100	6962				

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

Gage Factor: 0.349 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: 08-22531

Prestress: 35,000 psi

Temperature: 23.4 °C

Calibration Instruction: CI-VW Rebar

Date of Calibration: October 3, 2008

Cable Length: 36 ft.

Factory Zero Reading: 6980

Regression Zero: 7012

Technician: Erica

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7068	7067	7068		
1,500	7727	7729	7728	661	-0.18
3,000	8450	8448	8449	721	-0.18
4,500	9179	9177	9178	729	0.10
6,000	9901	9898	9900	722	0.11
100	7068				

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

Gage Factor: 0.350 microstrain/ digit (GK-401 Pos."B")

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

Note: The above calibration uses the linear regression method.

<u>Users are advised to establish their own zero conditions.</u>

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: 08-22532

Prestress: 35,000 psi

Temperature: 23.1 °C

Calibration Instruction: CI-VW Rebar

Date of Calibration: October 3, 2008

Cable Length: 34 ft.

Factory Zero Reading: 7041

Regression Zero: 7074

Technician: Erica

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7134	7125	7130		
1,500	7785	7782	7784	654	-0.14
3,000	8493	8496	8495	711	-0.23
4,500	9220	9214	9217	723	0.08
6,000	9932	9933	9933	716	0.15
100	7127				

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

Gage Factor: 0.353 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: 08-22533

Prestress: 35,000 psi

Temperature: 23.2 °C

Calibration Instruction: CI-VW Rebar

Date of Calibration: October 3, 2008

Cable Length: 34 ft.

Factory Zero Reading: 6737

Regression Zero: 6772

Technician: ERice

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6821	6824	6823		
1,500	7470	7475	7473	650	-0.14
3,000	8179	8179	8179	707	-0.07
4,500	8889	8888	8889	710	0.11
6,000	9590	9589	9590	701	-0.01
100	6825				

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 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

Date of Calibration: October 3, 2008

Serial Number: 08-22534

Cable Length: 32 ft.

Prestress: 35,000 psi

Factory Zero Reading: 7031

Temperature: 23.0 °C

Regression Zero: 7065

Calibration Instruction: CI-VW Rebar

Technician: Erica

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7117	7113	7115		
1,500	7784	7785	7785	670	-0.08
3,000	8512	8507	8510	725	0.04
4,500	9234	9229	9232	722	0.04
6,000	9954	9950	9952	721	0.00
100	7114				

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

Gage Factor: 0.350 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: 08-22535

Prestress: 35,000 psi

Temperature: 23.3 °C

Calibration Instruction: CI-VW Rebar

Date of Calibration: October 3, 2008

Cable Length: 32 ft.

Factory Zero Reading: 6752

Regression Zero: 6782

Technician: Erica

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6838	6834	6836		
1,500	7484	7484	7484	648	-0.24
3,000	8198	8198	8198	714	-0.06
4,500	8913	8909	8911	713	0.09
6,000	9622	9616	9619	708	0.06
100	6835				

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

Gage Factor: 0.354 microstrain/ digit (GK-401 Pos."B")

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

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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

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

APPENDIX C

CONSTRUCTION OF THE EQUIVALENT TOP-LOADED LOAD-SETTLEMENT CURVE

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

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

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

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

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

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

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

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

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

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

August, 2000

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

Figure A

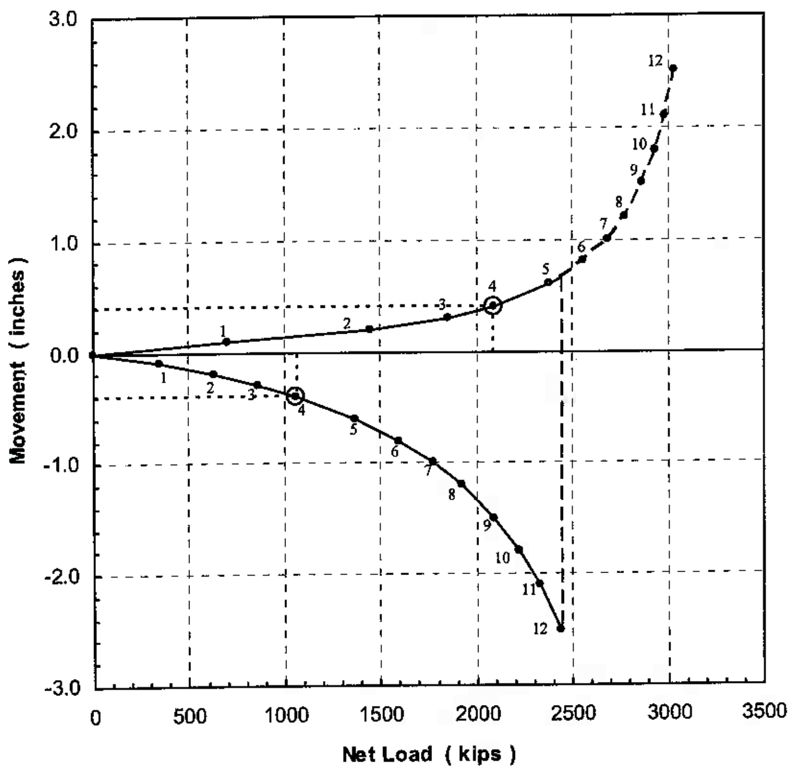
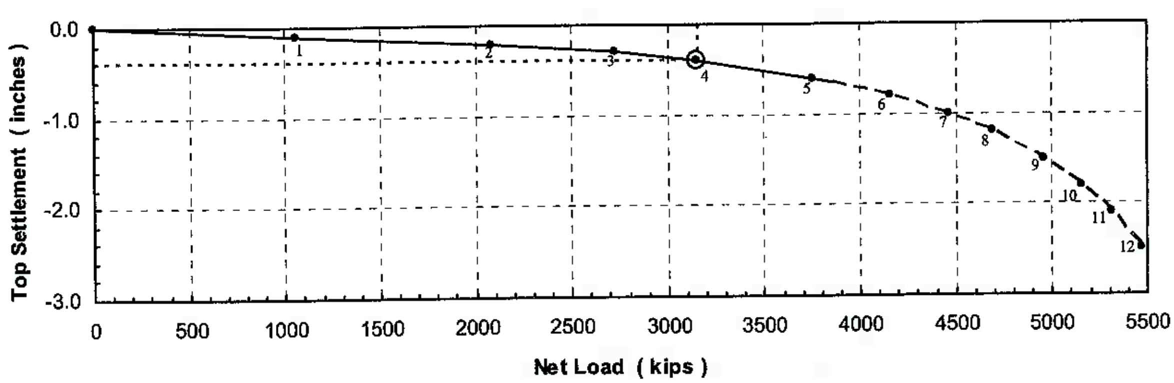
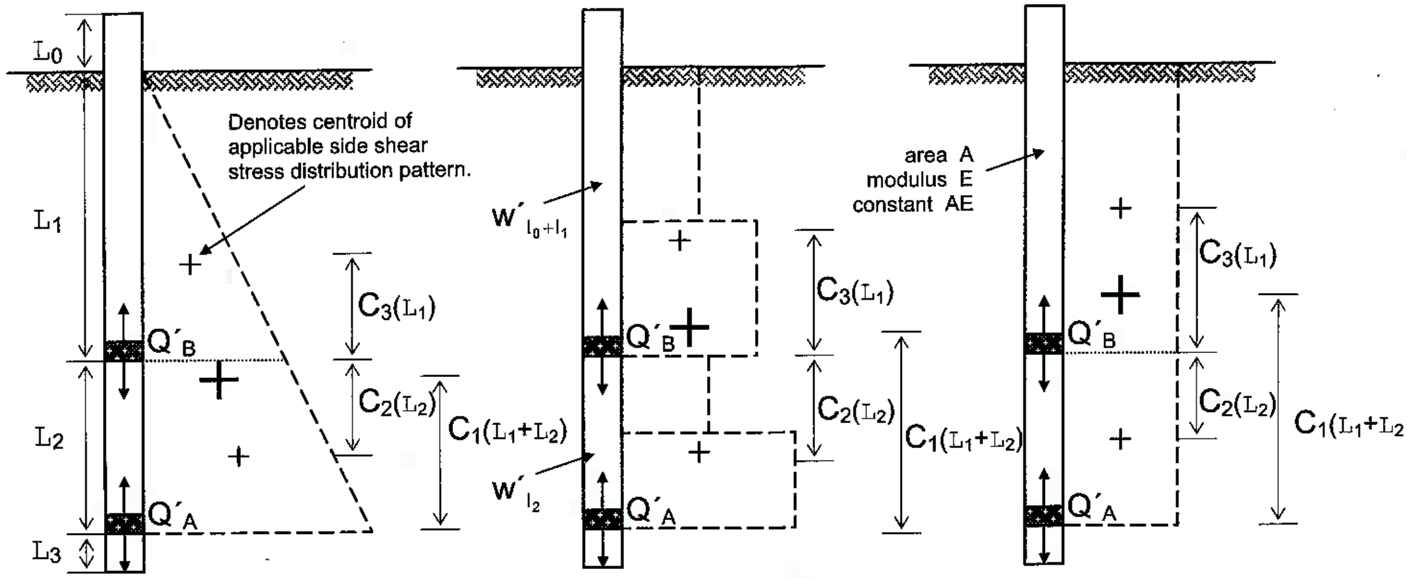


Figure B



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



1-Stage Single Level Test (Q'_A only):

$$\delta_{OLT} = \delta_{\uparrow(l_1+l_2)}$$

$C_1 = \frac{1}{3}$	Centroid Factor $= C_1$	$C_1 = \frac{1}{2}$
$\delta_{\uparrow(l_1+l_2)} = \frac{1}{3}\frac{Q'_{\uparrow A}(l_1+l_2)}{AE}$	$\delta_{\uparrow(l_1+l_2)} = C_1\frac{Q'_{\uparrow A}(l_1+l_2)}{AE}$	$\delta_{\uparrow(l_1+l_2)} = \frac{1}{2}\frac{Q'_{\uparrow A}(l_1+l_2)}{AE}$

3-Stage Multi Level Test (Q'_A and Q'_B): $\delta_{OLT} = \delta_{\uparrow l_1} + \delta_{\downarrow l_2}$

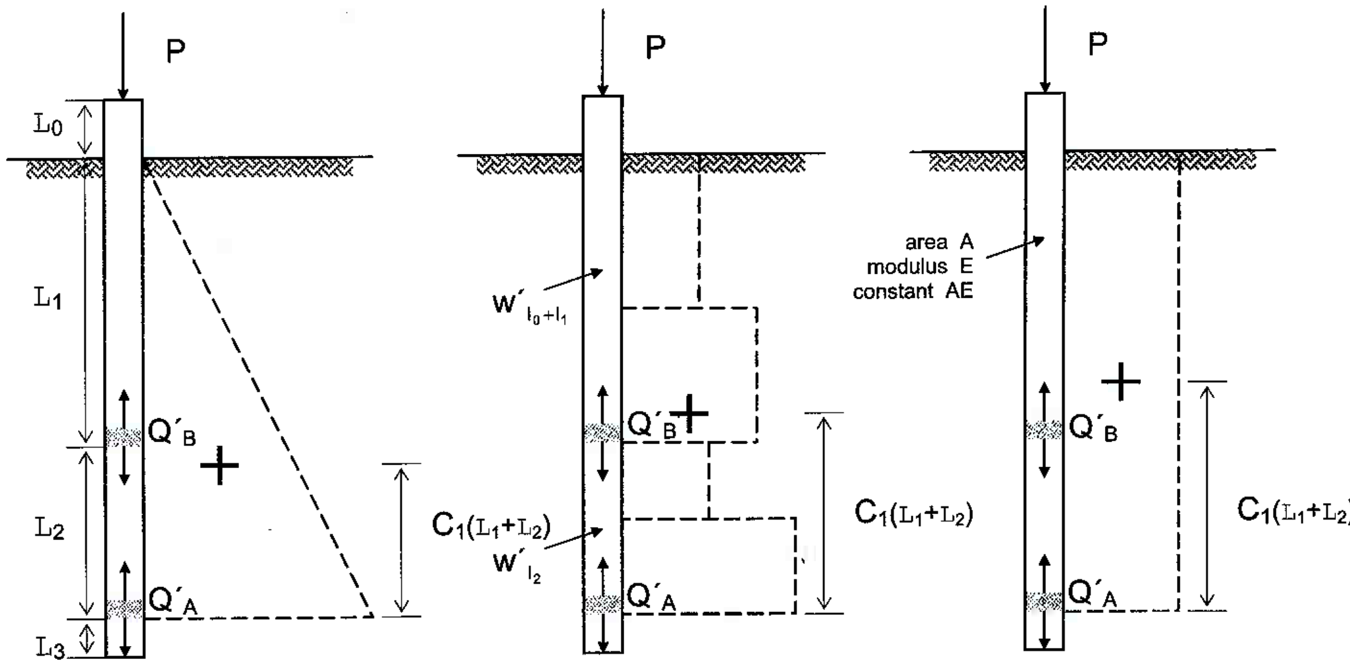
$C_3 = \frac{1}{3}$	Centroid Factor $= C_3$	$C_3 = \frac{1}{2}$
$\delta_{\uparrow l_1} = \frac{1}{3}\frac{Q'_{\uparrow B}l_1}{AE}$	$\delta_{\uparrow l_1} = C_3\frac{Q'_{\uparrow B}l_1}{AE}$	$\delta_{\uparrow l_1} = \frac{1}{3}\frac{Q'_{\uparrow B}l_1}{AE}$
$C_2 = \frac{1}{3}\left(\frac{3l_1+2l_2}{2l_1+l_2}\right)$	Centroid Factor $= C_2$	$C_2 = \frac{1}{2}$
$\delta_{\downarrow l_2} = \frac{1}{3}\left(\frac{3l_1+2l_2}{2l_1+l_2}\right)\frac{Q'_{\downarrow B}l_2}{AE}$	$\delta_{\downarrow l_2} = C_2\frac{Q'_{\downarrow B}l_2}{AE}$	$\delta_{\downarrow l_2} = \frac{1}{2}\frac{Q'_{\downarrow B}l_2}{AE}$

Net Loads:

$Q'_{\uparrow A} = Q_{\uparrow A} - W'_{l_0+l_1+l_2}$ $\quad$ $Q'_{\uparrow B} = Q_{\uparrow B} - W'_{l_0+l_1}$ $\quad$ $Q'_{\downarrow B} = Q'_{\downarrow B} + W'_{l_2}$

W' = pile weight, buoyant where below water table

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



Top Loaded Test: $\delta_{TLT} = \delta_{\downarrow l_0} + \delta_{\downarrow l_1+l_2}$

$\delta_{\downarrow l_0} = \dfrac{Pl_0}{AE}$	$\delta_{\downarrow l_0} = \dfrac{Pl_0}{AE}$	$\delta_{\downarrow l_0} = \dfrac{Pl_0}{AE}$
$C_1 = \dfrac{1}{3}$	$\text{Centroid Factor} = C_1$	$C_1 = \dfrac{1}{2}$
$\delta_{\downarrow l_1+l_2} = \dfrac{(Q'_{\downarrow A}+2P)}{3}\dfrac{(l_2+l_2)}{AE}$	$\delta_{\downarrow l_1+l_2} = \left[(C_1)Q'_{\downarrow A}+(1-C_1)P\right]\dfrac{(l_1+l_2)}{AE}$	$\delta_{\downarrow l_1+l_2} = \dfrac{(Q'_{\downarrow A}+P)}{2}\dfrac{(l_1+l_2)}{AE}$

Net and Equivalent Loads:

$Q'_{\downarrow A} = Q_{\downarrow A} - W'_{l_0+l_1+l_2}$ $\qquad P_{single} = Q'_{\downarrow A} + Q'_{\uparrow A}$ $\qquad P_{multi} = Q'_{\downarrow A} + Q'_{\uparrow B} + Q'_{\downarrow B}$

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

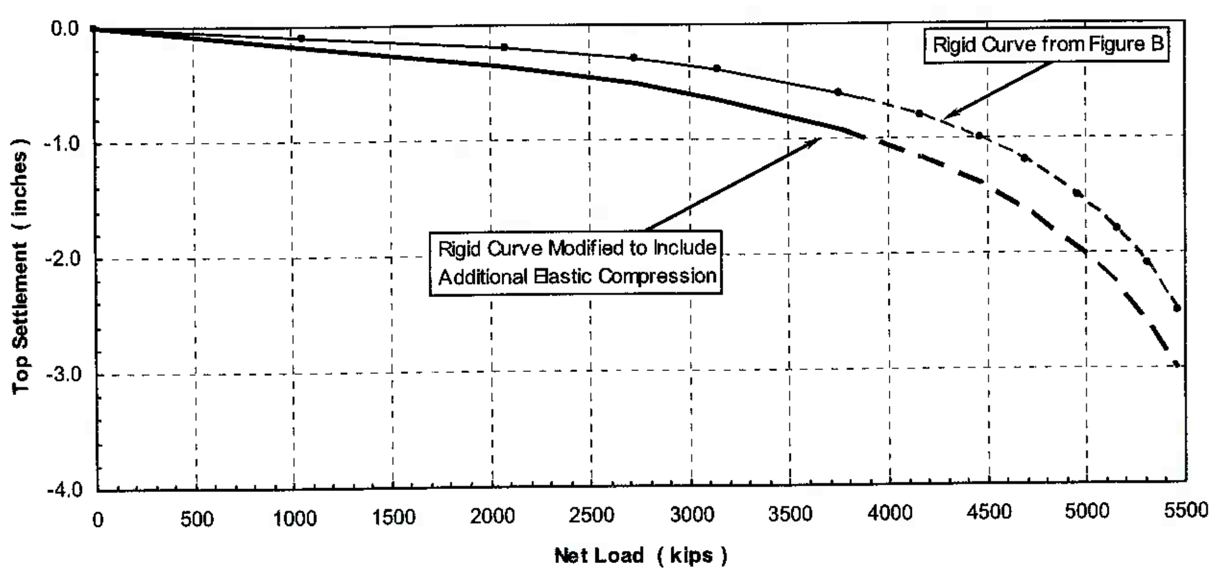
Example Calculation for the Additional Elastic Compression Correction For Single Level Test (English Units)

Given:

C_1	=	0.441	
AE	=	3,820,000	kips (assumed constant throughout test)
I_0	=	5.9	ft
I_1	=	30.0	ft (embedded length of shaft above O-cell)
I_2	=	0.00	ft
I_3	=	0.0	ft
Shear reduction factor	=	1.00	(cohesive soil)

Δ_{OLT} (in)	$Q'_{\downarrow A}$ (kips)	$Q'_{\uparrow A}$ (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

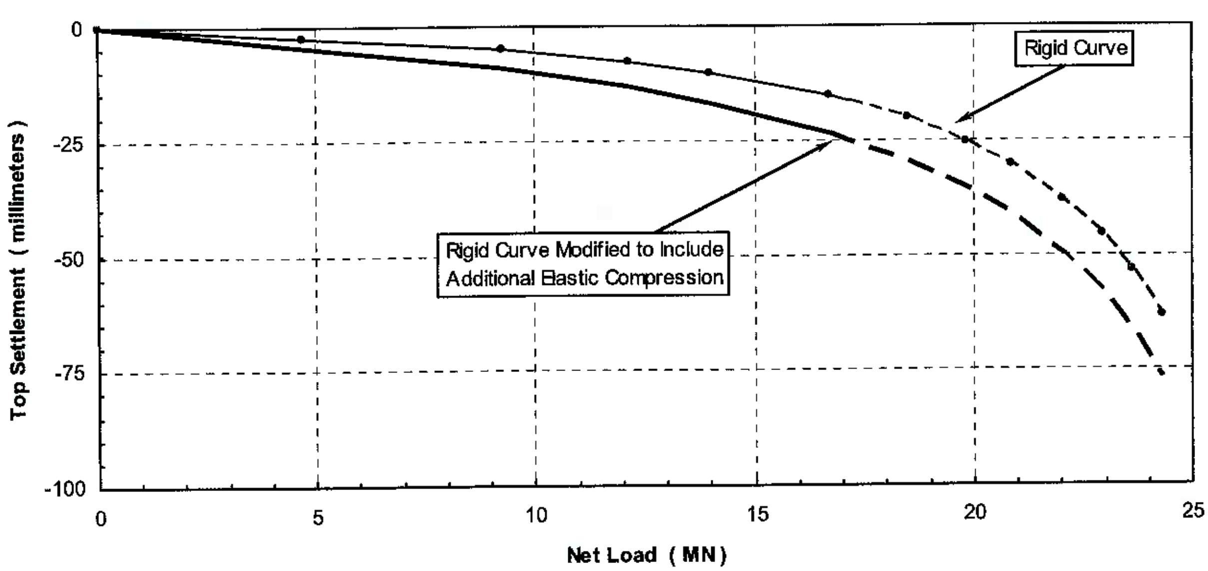


Example Calculation for the Additional Elastic Compression Correction For Single Level Test (SI Units)

Given:				
	C_1	=	0.441	
	AE	=	17,000	MN (assumed constant throughout test)
	I_0	=	1.80	m
	I_1	=	14.69	m (embedded length of shaft above mid-cell)
	I_2	=	0.00	m
	I_3	=	0.0	m
Shear reduction factor		=	1.00	(cohesive soil)

Δ_{OLT} (mm)	$Q'_{\downarrow A}$ (MN)	$Q'_{\uparrow A}$ (mm)	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



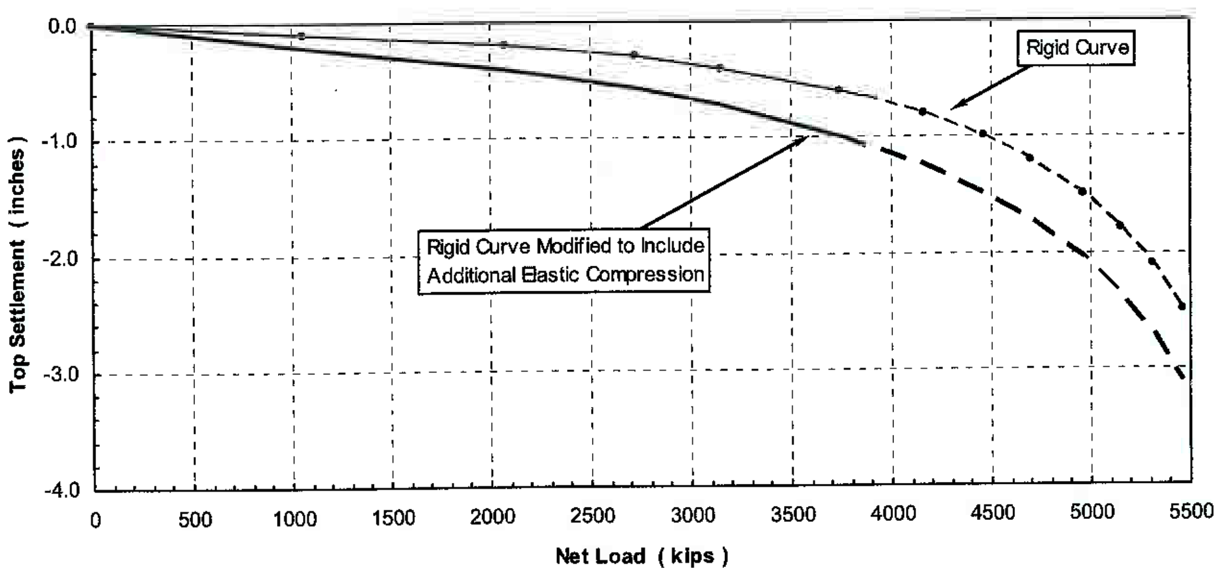
Example Calculation for the Additional Elastic Compression Correction For Multi Level Test (English Units)

Given:

C_1 = 0.441
C_2 = 0.579
C_3 = 0.396
AE = 3,820,000 kips (assumed constant throughout test)
I_0 = 5.9 ft
I_1 = 30.0 ft (embedded length of shaft above mid-cell)
I_2 = 18.2 ft (embedded length of shaft between O-cells)
I_3 = 0.0 ft
Shear reduction factor = 1.00 (cohesive soil)

Δ_{OLT} (in)	$Q'_{\downarrow A}$ (kips)	$Q'_{\downarrow B}$ (kips)	$Q'_{\uparrow A}$ (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



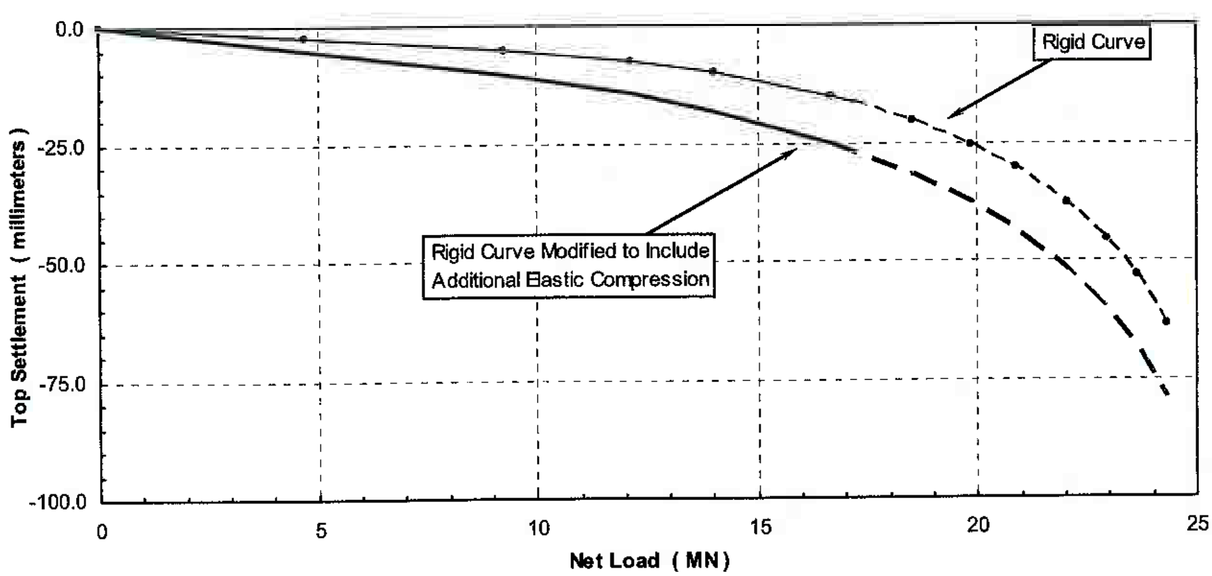
Example Calculation for the Additional Elastic Compression Correction For Multi Level Test (SI Units)

Given:

	C_1	=	0.441	
	C_2	=	0.579	
	C_3	=	0.396	
	AE	=	17,000	MN (assumed constant throughout test)
	I_0	=	1.80	m
	I_1	=	9.14	m (embedded length of shaft above mid-cell)
	I_2	=	5.55	m (embedded length of shaft between O-cells)
	I_3	=	0.00	m
Shear reduction factor		=	1.00	(cohesive soil)

Δ_{OLT} (mm)	$Q'_{\downarrow A}$ (MN)	$Q'_{\downarrow B}$ (MN)	$Q'_{\uparrow B}$ (mm)	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	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

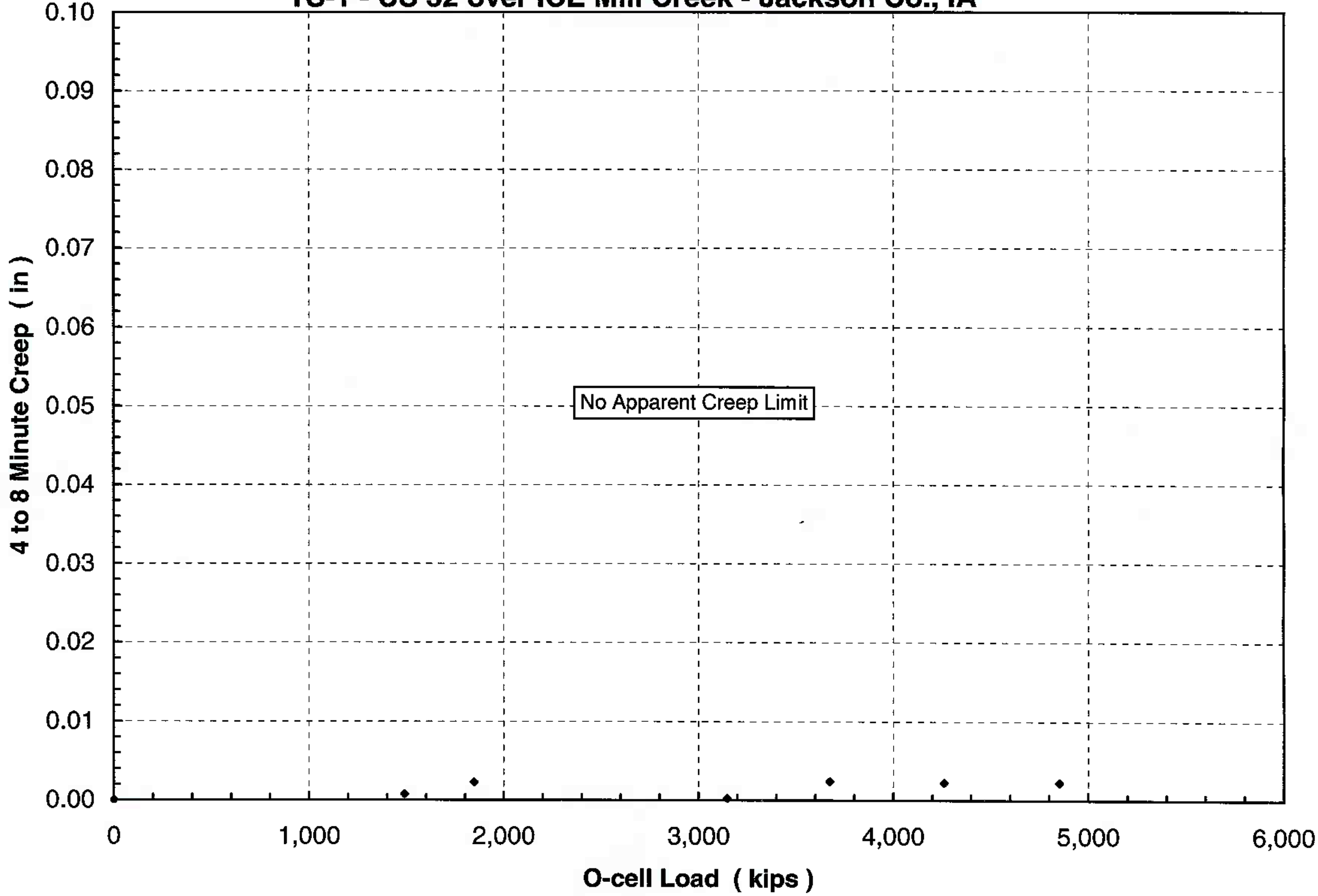


APPENDIX D

O-CELL METHOD FOR DETERMINING CREEP LIMIT LOADING

Combined End Bearing and Lower Side Shear Creep Limit

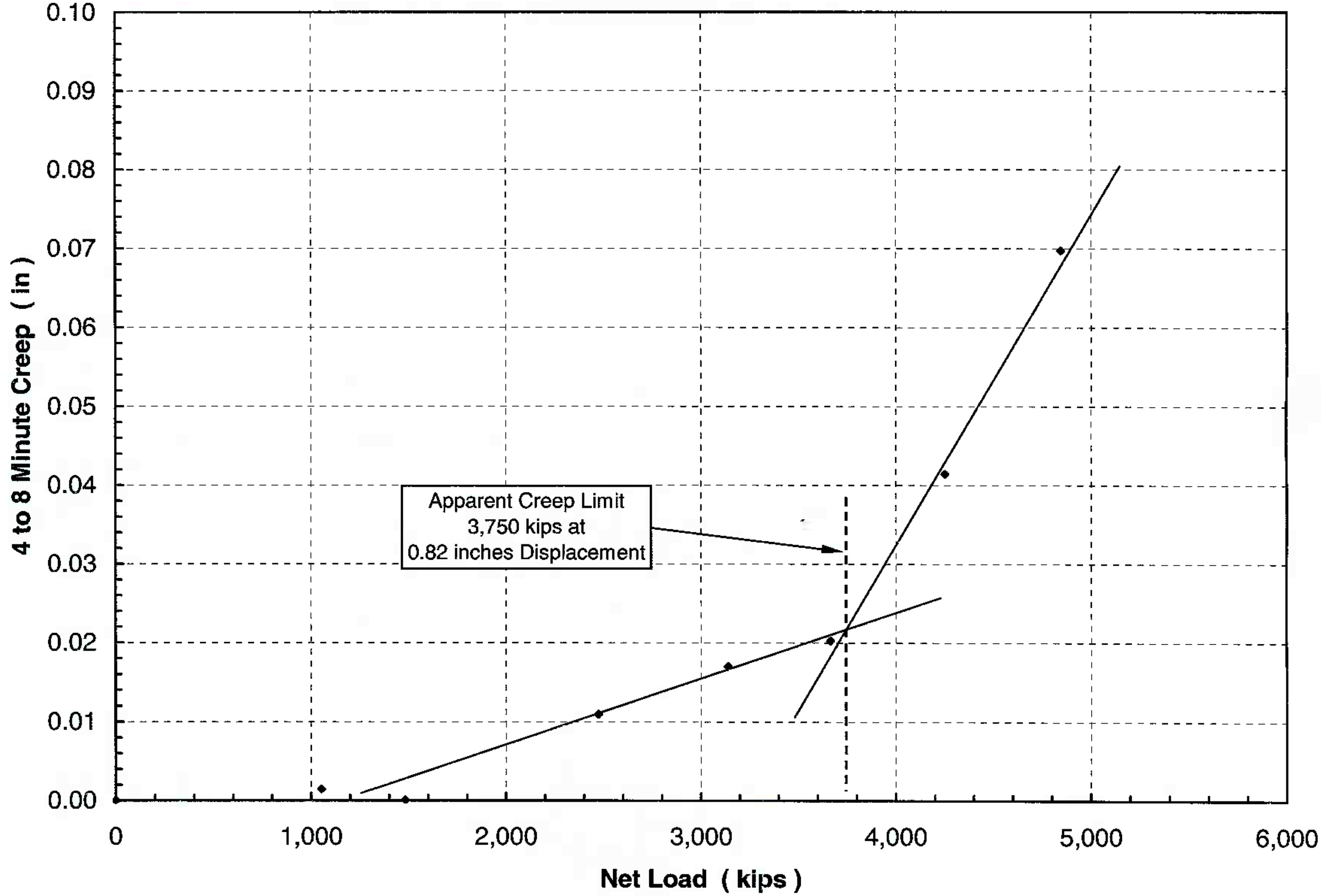
TS-1 - US 52 over ICE Mill Creek - Jackson Co., IA



Appendix D, Figure 1

Upper Side Shear Creep Limit

TS-1 - US 52 over ICE Mill Creek - Jackson Co., IA



Appendix D, Figure 2

O-CELL METHOD FOR DETERMINING A CREEP LIMIT LOADING ON THE EQUIVALENT TOP-LOADED SHAFT (September, 2000)

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

To our knowledge, Housel (1959) first proposed the method described below for determining the creep limit. Stoll (1961), Bourges and Levillian (1988), and Fellenius (1996) provide additional references. This method also follows from long experience with the pressuremeter test (PMT). Figure 8 and section 9.4 from ASTM D4719-94, reproduced below, show and describe the creep curve routinely determined from the PMT. The creep curve shows how the movement or strain obtained over a fixed time interval, 30 to 60 seconds, changes versus the applied pressure. One can often detect a distinct break in the curve at the pressure P_e in Figure 8. Plastic deformations may become significant beyond this break loading and progressively more severe creep can occur.

Definition: Similarly with O-cell testing using the ASTM Quick Method, one can conveniently measure the additional movement occurring over the final time interval at each constant load step, typically 4 to 8 minutes. A break in the curve of load vs. movement (as at P_e with the PMT) indicates the creep limit.

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

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

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

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

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

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

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

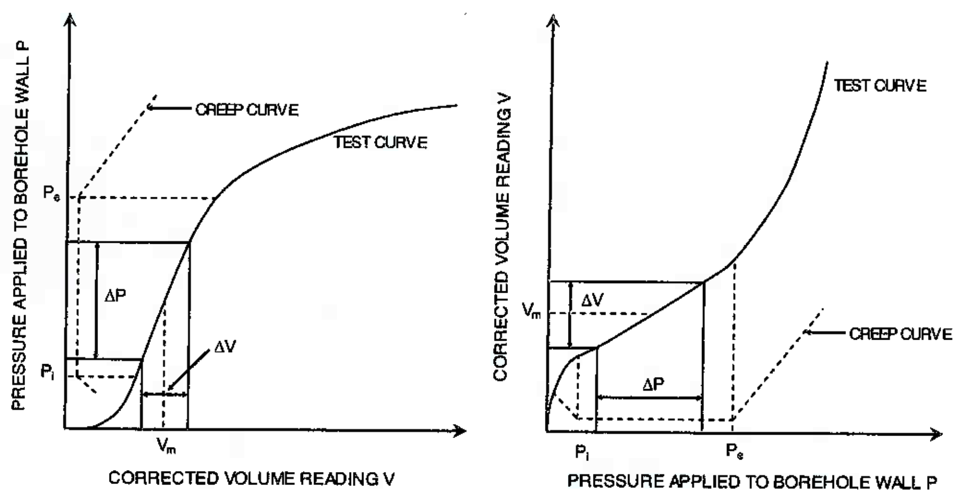


FIG. 8 Pressuremeter Test Curves for Procedure A

References

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

Stoll, M.U.W. (1961, Discussion, Proc. 5th ICSMFE, Paris, Vol. III, pp. 279-281.

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

Fellenius, Bengt H. (1996), Basics of Foundation Design, BiTech Publishers Ltd., p.79.

APPENDIX E

SOIL BORING LOG

BORING LOG No. TB 1

BORING NO.	LOCATION OF BORING	ELEVATION	DATUM	DRILLER	LOGGER
TB 1	Test Shaft	597.82 feet	IDOT Site Plan	DAH	JLW

WATER LEVEL OBSERVATIONS				TYPE OF SURFACE	DRILL RIG
WHILE DRILLING	END OF DRILLING	24 HOURS AFTER DRILLING		Grass	Mobile B-57
				DRILLING METHOD	TOTAL DEPTH
8 feet	N/A	N/A		3-1/4" HSA and NQ2 Coring	41.8 feet

DEP. FT.	SAMPLE DATA: SAMPLE NO. & TYPE	"N" BLOWS /RQD	% REC.	SOIL DESCRIPTION: COLOR, MOISTURE, CONSISTENCY / GEOLOGIC DESCRIPTION & OTHER REMARKS	USCS CLASS.	LABORATORY DATA: % MC	DRY DENS. pcf	Qu psi	ELEV. FT.
				Brown and dark brown, Moist LEAN TO FAT CLAY with gravel					
									594
	S1	10	95			18.5			
				Increased fractured rock content with depth	CL/CH				
6									
▽									▽
	S2	9	95			19.2			
				OVERBURDEN 10.0'					588
	S3	50/4"	50	Light grey to grey, Moist, Hard MODERATELY WEATHERED DOLOMITE					
	NQ2-1	0(RQD)	43	11.1'					
12				ORDOVICIAN BEDROCK					
				Light grey to grey, Moist, Hard SLIGHTLY WEATHERED TO FRESH DOLOMITE 3/4" and 1" void with Pyrite near 12 and 12.6 feet		2.2	161	5,170	
	NQ2-2	0.60	100						
				3" Shale seam near 15.2 feet		1.3	164	1,850	582
				1" void with Pyrite near 17 feet					
18									
	NQ2-3	1.00	100			4.2	152	2,950	
									576
						1.9	163	3,040	
24	NQ2-4	0.75	96						
						1.6	165	4,930	
									570
						1.7	163	6,360	
30	NQ2-5	0.90	100						
						1.4	156	7,320	
									564
	NQ2-6	0.96	100			1.0	158	6,560	
36									
				Brown between 36.8 and 40.8 feet MODERATELY WEATHERED DOLOMITE between 37.7 and 38.1 feet					
	NQ2-7	0.63	86			3.9	153	2,260	558
42				ORDOVICIAN BEDROCK 41.8' Bottom of Boring @ 41.8'		2.6	150	2,830	
									552
48									

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

PROJECT: Test Shaft Confirmation Boring
LOCATION: US 52 Over ICE & Mill Creek, Jackson Co, IA
JOB NO.: 086187
DATE: 10-9-2008