DATA REPORT ON DRILLED SHAFT LOAD TESTING (OSTERBERG METHOD)

Ellsworth, KS- K-156 over Union Pacific Railroad & Side Road

Prepared for: Kansas Dept. of Transportation
915 SW Harrison, 9th Floor,
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Attention: Richard Elliott
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PROJECT NUMBER: LT-8790, August 30, 2001

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

August 28, 2001

Kansas Dept. of Transportation
915 SW Harrison, 9th Floor,
Topeka, KS 66612-1568

Attention: Richard Elliott

Data Report: Ellsworth, KS - K-156 over Union Pacific Railroad & Side Road
Location: Ellsworth County, KS

Loadtest Inc. performed an Osterberg Cell load test for Kansas Dept. of Transportation on Test Shaft (LTI project LT-8790). The test was carried out on August 23, 2001 by LOADTEST Inc. under the direction of Mr. Shing Pang and Mr. Dave Jakstis. All of the 1, 2, 4 and 8 minute data and a summary of the results are contained within this Data Report.

Representatives of the Kansas Department of Transportation and Midwest Foundations Co. observed the test. Throughout this report, we use English units as primary and SI units as secondary.

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

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SITE CONDITIONS AND TEST SHAFT INSTALLATION

Site Sub-surface Conditions: The sub-surface stratigraphy at the test shaft location is reported to consist of silty clay underlain by loose to dense coarse sand and gravel down to elevation +451 meters (+1480 feet). Below elevation +451 meters to an undetermined depth, sandstone was present. A boring log, located in the vicinity of the shaft, is presented in Appendix F.

Test Shaft Construction: Midwest Foundations Co. constructed the dedicated test shaft socketed in rock on August 16, 2001. Assembly and installation of the O-cell™ and instrumentation was carried out under the direction of Shing Pang and Dave Jakstis of LOADTEST Inc. The shaft was constructed with a total length of 19.0 feet (5.79 meters). The test shaft was constructed wet using polymer to a tip elevation of +1454.8 feet (+443.42 meters). The shaft was started with a 60-inch (1524-mm) O.D. temporary casing. A 48-inch (1219-mm) O.D. temporary inner casing was inserted as the drilling progressed. An auger and core barrel were used for drilling the shaft. The bottom of the shaft was cleaned with a cleaning bucket after drilling. After the carrying frame and O-cell™ assembly was inserted in the shaft, concrete was placed by pump through a 4-inch (122-mm) O.D. pipe into the base of the shaft until the top of the concrete reached an elevation of +1473.8 feet (+449.21 meters). The O-cell™ was located 3.74 feet (1.14 meters) above the tip of shaft. No unusual problems occurred during construction of the shaft. Both the outer and inner temporary casing were left in place during testing and removed afterward. Note: The tip of both casings was above the top of concrete. Table B contains a summary of dimensions, elevations and shaft properties used in the data evaluations.

Shaft Instrumentation: The test assembly included a single 26-inch (660-mm) O-cell™. The base of the O-cell™ assembly was located 3.7 feet (1.14 meters) above the tip of shaft. A pressure vs. load calibration of the O-cell™ was carried out to 3083 kips (13.71 MN) by American Equipment and Fabricating Corporation prior to delivery to the test site (see Appendix B). Standard O-cell™ instrumentation included three LVWDTs (Linear Vibrating Wire Displacement Transducers - Geokon Model 4450 series) positioned between the lower and upper plates to measure O-cell™ expansion (Table 3). Two lengths of ½-inch (13 mm) steel pipe (180 degrees opposed) were attached to the test shaft assembly to measure compression of the shaft between the O-cell™ and the top of the shaft with traditional telltales that were installed later. In addition, compression of the pile above the top O-cell™ assembly was measured by two telltales extending to the ground surface. Telltale movements were measured by LVDTs at the ground surface (Table 1).

Two levels of two sister bar vibrating wire strain gages 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 used to assess the side shear load transfer of the shaft above the Osterberg cell. The strain gages were positioned as directed by the Loadtest Inc.

The test shaft assembly also included two lines of PVC pipe, starting at the top-of-shaft and terminating at the top of the bottom plate to vent the break in the shaft between upward and downward movement and the resulting annular void. If desired it permits the application of excess fluid pressure to reduce the possibility of soil entering the void. It also provides access for any final grouting to fill the void after completing the testing.

TESTING

Test Arrangement: Telltales located between the top of the O-cell™ and the top of the shaft were provided and installed from the top of the O-cell™ to the top of shaft in pre-installed steel pipe (see above). LVDTs (RDP) at the top of shaft were attached to the traditional telltales. Two LVDTs attached to a reference beam were provided to measure the top of shaft movement. The reference beam consisted of a 20 feet (6 meters) steel wide flange section supported on wood dunnage. The supports were located approximately one and a half shaft diameters from the center of the test shaft. The beam was fully protected (covered) by a tarp over a frame. An automated Leica surveying level (NA3003) was provided in order to monitor the reference beam to a precision of 0.0004 inches (0.01 mm).

Both a Bourdon-type pressure gage (0-10,000 psi) 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 although the pressure transducer read irratically for a short time during the test.

Data Acquisition: All of the movement indicators, LVWDTs and strain gages were connected to a data logger (Data Electronics - Model 615 Datataker®). The logger, in turn was connected to a laptop computer. This arrangement allowed movement indicator, LVWDT, strain gage and thermistor readings to be recorded and stored automatically at 30 second intervals during the test. It also allowed the automatic importation of all test data into a laptop computer for real-time display and additional data back-up. The Leica (NA3003) data was imported real-time directly to a lap top computer set to the same time as the data logging system.

Note: Calibrations for all instrumentation used during this test are available. Required calibrations are included in <u>Appendix B</u>.

Testing Procedures: We applied the load increments using the Quick Load Test Method (ASTM D1143), holding each successive load increment constant for eight minutes by manually adjusting the O-cell™ pressure. We used approximately one minute to move between increments. The data logger automatically recorded the instrument readings every 30 seconds, but herein we report only the one, two, four and eight minute readings during each increment of maintained load. The various plotted results generally use the one, two, four and eight minute readings, but the creep results use the difference between the four and eight minute readings.

As with all our tests, we begin the load test by pressurizing the O-cell™ in order to break the tack welds that hold the cell closed (for handling and construction of the shaft) and to form the fracture plane in the concrete surrounding the base of the O-cell™. After the break occurs, we immediately release the pressure and then begin the test. Zero readings for all instrumentation are taken prior to the preliminary weld-breaking load-unload cycle, which in this case involved a maximum applied pressure of 1050 psi (7.25 MPa).

The Osterberg cell load test was conducted as follows: The 26-inch (660-mm) diameter O-cell™, with its base located 3.7 feet (1.14 meters) above the tip of shaft was pressurized to assess the base resistance below the O-cell™ assembly and the side shear above the O-cell™ assembly. The O-cell™ was pressurized in 9 loading increments to 4100 psi (28.3 MPa) resulting in a bi-directional load of 1513 kips (6.73 MN). The loading was halted after load interval 1L-9 because the O-cell™ was nearing its maximum stroke of 6 inches (150 mm).

SUMMARY AND RESULTS

General: The loads applied by the O-cell™ act in two opposing directions, resisted by side shear above the O-cell™ and by base resistance below the O-cell™. Gross, or applied O-cell™ load is defined as load applied above and below the O-cell™ as calculated from the cell's calibration. Net load is defined as the O-cell™ load minus the buoyant weight of the shaft above the cell for upward movements. Net load is used in this report when analyzing average net unit shear values above the cell and also when reconstructing an equivalent top load curve for top loaded compression shafts. For this test we calculated a buoyant weight of 14.1 kips (0.062 MN).

The top of shaft movement depends on the reference beam movement. The beam was monitored during the test. The maximum range of movement for the center of the beam was 0.02 inches (0.6 mm) over the duration of the test. Due to the small beam movement, no adjustment was made.

Side Shear: The maximum upward net load applied to the side shear was 6.7 MN (1,499 kips) which occurred at load interval 1L-9 (Tables 3, Figure 1). At this loading, the total upward movement of the top of O-cell™ assembly was 0.132 inches (3.3 mm). The following net unit side shear estimates are based on the strain gage data which appear in Table 4 and the shaft stiffnesses computed below.

At the time of testing, the concrete unconfined compressive strength was reported to be 4,550 psi (31.4 MPa). We used the ACI formula ($Ec=57000\sqrt{f'c}$) to calculate an elastic modulus for the concrete. This, combined with the area of reinforcing steel, was used to determine a combined shaft stiffness of AE = 5,500,000 kips (24,300 MN) for the nominal shaft diameter. Estimated net unit side shear values for the shaft based on the strain gage data, estimated shaft stifnesses and shaft area are as follows:

Table A: Net Unit Side Shear Values (Based on Net Loads)

Load Transfer Zone	**Direction* of Loading**	**Load Increment**	**Net Unit Side* Shear**
Average Socket – Top of Concrete to O-cell™	↑	1L-9	8.93 ksf (428 kPa)
Top of Shaft to Strain Gage Level 2	↑	1L-9	9.00 ksf (431 kPa)
Strain Gage Level 2 to Strain Gage Level 1	↑	1L-9	6.46 ksf (309 kPa)
Strain Gage Level 1 to O-cell™	↑	1L-9	10.08 ksf (483 kPa)

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

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

Side shear load distribution curves generated from strain gage data are shown in Figure 3. A unit side shear value for the shaft between the Level 1 Strain Gages and the O-cell™ was calculated for 1L-9 to obtain an estimate of the base shear component of resistance to the downward movement below the O-cell™.

End Bearing: The maximum O-cell™ load applied to the base of the shaft was 1513 kips (6.73 MN) which occurred at load interval 1L-9 (Tables 3, Figure 1). At this loading, the total downward movement of the O-cell™ base was 5.485 inches (139.3 mm). The base resistance includes a small component of base shear which must be subtracted to obtain unit end bearing values. The shear component of resistance for the 3.7 feet (1.14 meter) shaft base below the O-cell™ is calculated to be 413 kips (1.84 MN) assuming a unit side shear value of 10.08 ksf (483 kPa) and a shaft diameter of 42 inches (1067 mm). The maximum applied load to end bearing is then 1099.6 kips (4.9 MN) and the end-bearing pressure applied at the tip of the shaft is calculated to be 114 ksf (5,470 kPa).

Creep Limit: See Appendix D for our O-cell™ method for determining creep limit. The side shear creep data (Table 3) indicate that a creep limit was not reached at a movement of 0.13 in (3.30 mm). The combined end bearing and lower side shear creep data (Table 3) indicate that a creep limit of 1050 kips (4.7 MN) was reached at a movement of 0.425 inches (10.8 mm) (Figure 5). A top loaded shaft will begin significant creep when 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 2057 kips (9.15 MN) by some unknown amount.

Equivalent Top Load: Figure 2 presents the equivalent top load-settlement curve. The unadjusted 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 can be an important component of the settlements involved, the equivalent top load curve includes an adjustment for the additional elastic compression which would occur in a top-load test. The darker curve as described in Procedure Part II of Appendix C includes such an adjustment. Note that a top loaded shaft extending to the surface will have additional elastic compression not included in Fig. 2 .

The test shaft was successfully loaded to a combined side shear and end bearing of more than 3026 kips (13.46 MN). For a top loading of 5.19 MN (1166 kips), the adjusted test data indicate this shaft would settle approximately 0.051 inches (1.3 mm) of which 0.01 inches (0.22 mm) is estimated elastic compression. The equivalent top load curve is shown in Figure 2. Note: as explained previously, the equivalent top load curve applies to a loading duration of four minutes. Creep effects will reduce the ultimate resistance of both components and increase pile top movement for a given loading over longer times. The Engineer can estimate such additional creep effects by suitable extrapolation of time effects using the creep data presented herein. However, our experience suggests that such corrections are small and perhaps negligible for top loadings below the creep limit indicated in above.

Shaft Compression Telltales: The measured maximum shaft compression, averaged from 2 telltales, is 0.015 inches (0.37 mm). Using the shaft nominal diameters (Table B and Figure A) and a weighted average shaft stiffness of 5,500,000 ksi (24,300 MPa) for the shaft and the load distribution for 1L-9 in Figure 2, we calculated an elastic compression of 0.017 inches (0.43 mm) over the length of the compression telltales. We believe this agreement provides good evidence that the assumed shaft stiffnesses are reasonable and that the O-cell™ loaded the shaft in accord with the calibration used herein.

O-cell™ Tilting: The three LVWDTs measuring O-cell™ expansion allow us to evaluate the tilt of the bottom plate. Table 3 show these measurements. We calculate a maximum tilt angle of 1.1 degrees and a total tilt of 0.77 inches (19.7

mm) across the nominal 42-inch (1067-mm) diameter of the bottom of the shaft at the 1L-9 maximum loading, assuming only the bottom plate tilts.

The analysis provided 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/her own conclusions with regard to the analytical information.

Prepared for LOADTEST, INC. by

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For LOADTEST, Inc.

Reviewed by

Robert C. Simpson, M.S.E.,
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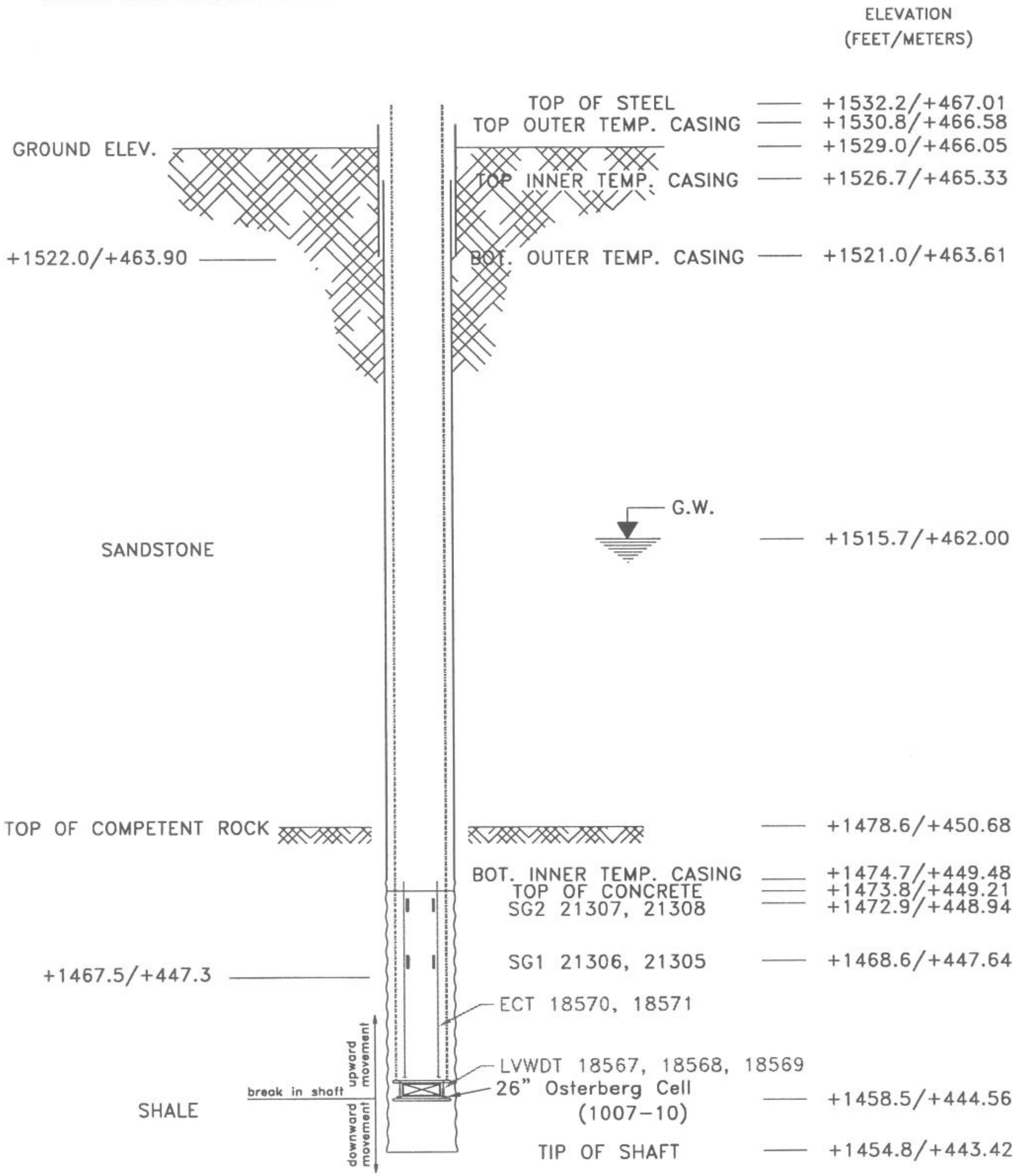
For John H. Schmertmann, Inc.

TABLE B: SUMMARY OF DIMENSIONS, ELEVATIONS, AREAS & PROPERTIES FOR ANALYSIS PURPOSES

Shaft:			
Nominal shaft diameter: EL+1473.8 to EL+1454.8	=	42 inches	1067 mm
O-cell size: (Serial nos.: 1007-10, 0, 0)	=	26 inches	660 mm
Length of concrete from break at base of cell to tip	=	3.7 feet	1.1 meters
Shaft shear area from break at base of cell to tip	=	41.0 $feet^2$	3.81 $meters^2$
Shaft end area	=	9.6 $feet^2$	0.89 $meters^2$
Weight of shaft from break at base of cell to top of shaft	=	14.1 kips	0.06 MN
Estimated shaft unit stiffness: EL+1473.8 to EL+1458.5	=	5.47E+06 kips	24.3 GN
Elevation of top of shaft concrete	=	+1473.8 feet	+449.2 meters
Elevation of ground surface (mud line)	=	+1473.8 feet	+449.2 meters
Elevation of break at base of O-cell™	=	+1458.5 feet	+444.6 meters
Elevation of shaft tip	=	1454.8 feet	+443.4 meters
Casings:			
Elevation of top of inner temporary casing: 48 O.D.	=	+1526.7 feet	+465.3 meters
Elevation of top of outer temporary casing: 60 O.D.	=	+1530.8 feet	+466.6 meters
Elevation of bottom of outer temporary casing: 60 O.D.	=	+1521.0 feet	+463.6 meters
Elevation of bottom of inner temporary casing: 48 O.D.	=	+1474.7 feet	+449.5 meters
Compression Sections:			
Elevation of top of telltale used for upper shaft compression	=	+1473.8 feet	+449.2 meters
Elevation of bottom of telltale used for upper shaft compression	=	+1459.9 feet	+445.0 meters
Strain Gages:			
Elevation of strain gage Level 2	=	+1472.9 feet	+448.9 meters
Elevation of strain gage Level 1	=	+1468.7 feet	+447.6 meters
Miscellaneous:			
Top plate diameter	=	36.0 inches	914 mm
Top plate thickness	=	2.0 inches	50.8 mm
Bottom plate diameter	=	36.0 inches	914 mm
Bottom plate thickness	=	2.0 inches	50.8 mm
Water elevation	=	+1515.7 feet	+462.0 meters
LVWDT radii	=	14.5 inches	368.3 mm
LVWDT orientation	=	0, 180, 285	degrees

NOTE:
- NOMINAL SHAFT DIAMETER 1067 mm



LOADTEST INC	2631-D NW 41st St. Gainesville, FL 32606 Phone 800-368-1138 FAX (352) 378-3934	SCHEMATIC SECTION OF TEST SHAFT	LT-8790 K-156 Over Union Pacific RR Ellsworth, KS FIGURE A

Osterberg Cell Load-Movement Curves

Ellsworth, KS - K-156 over Union Pacific Railroad Side Road - Test Shaft

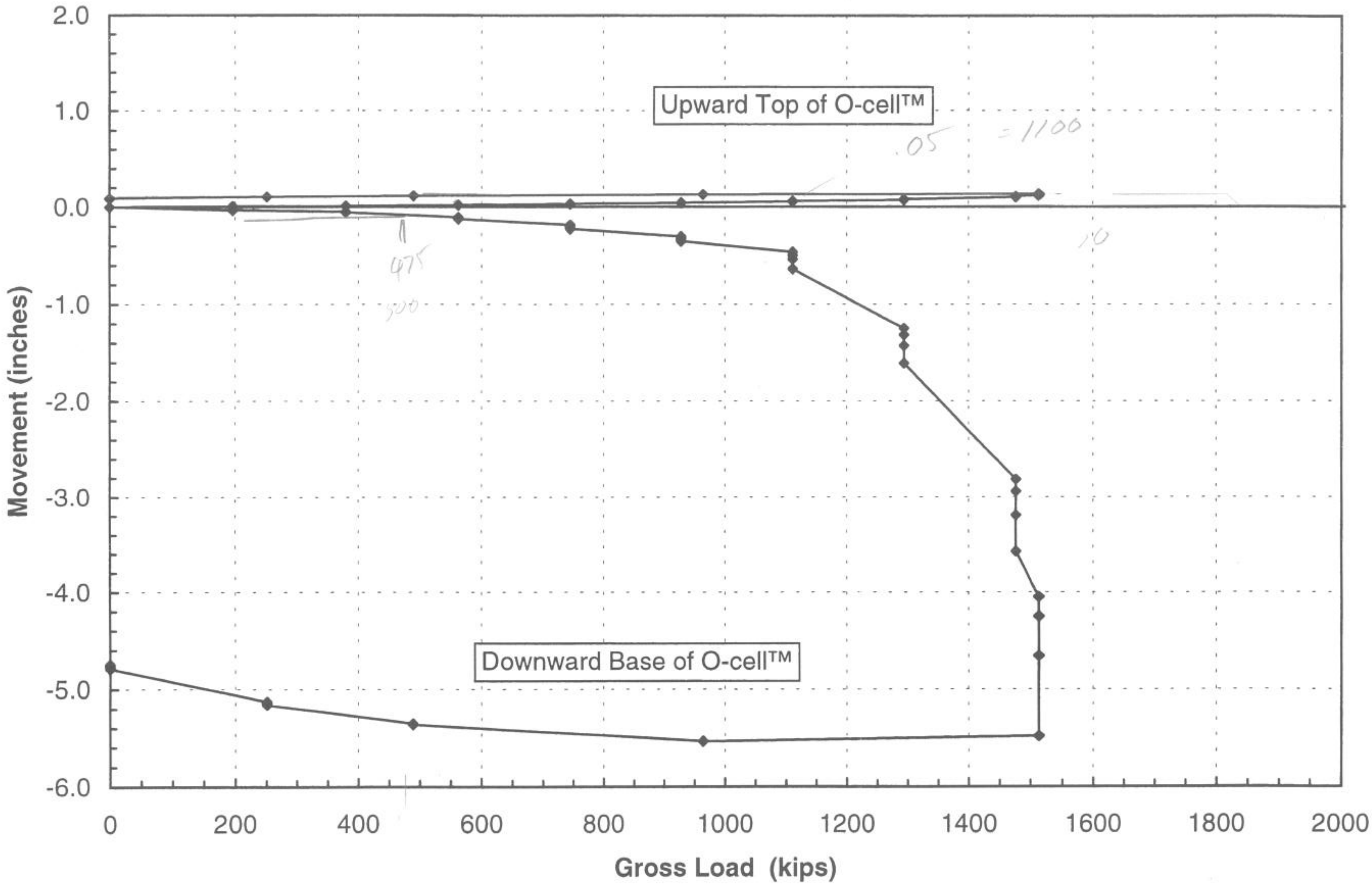


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Figure 1 of 5

Equivalent Top Load-Movement Curves

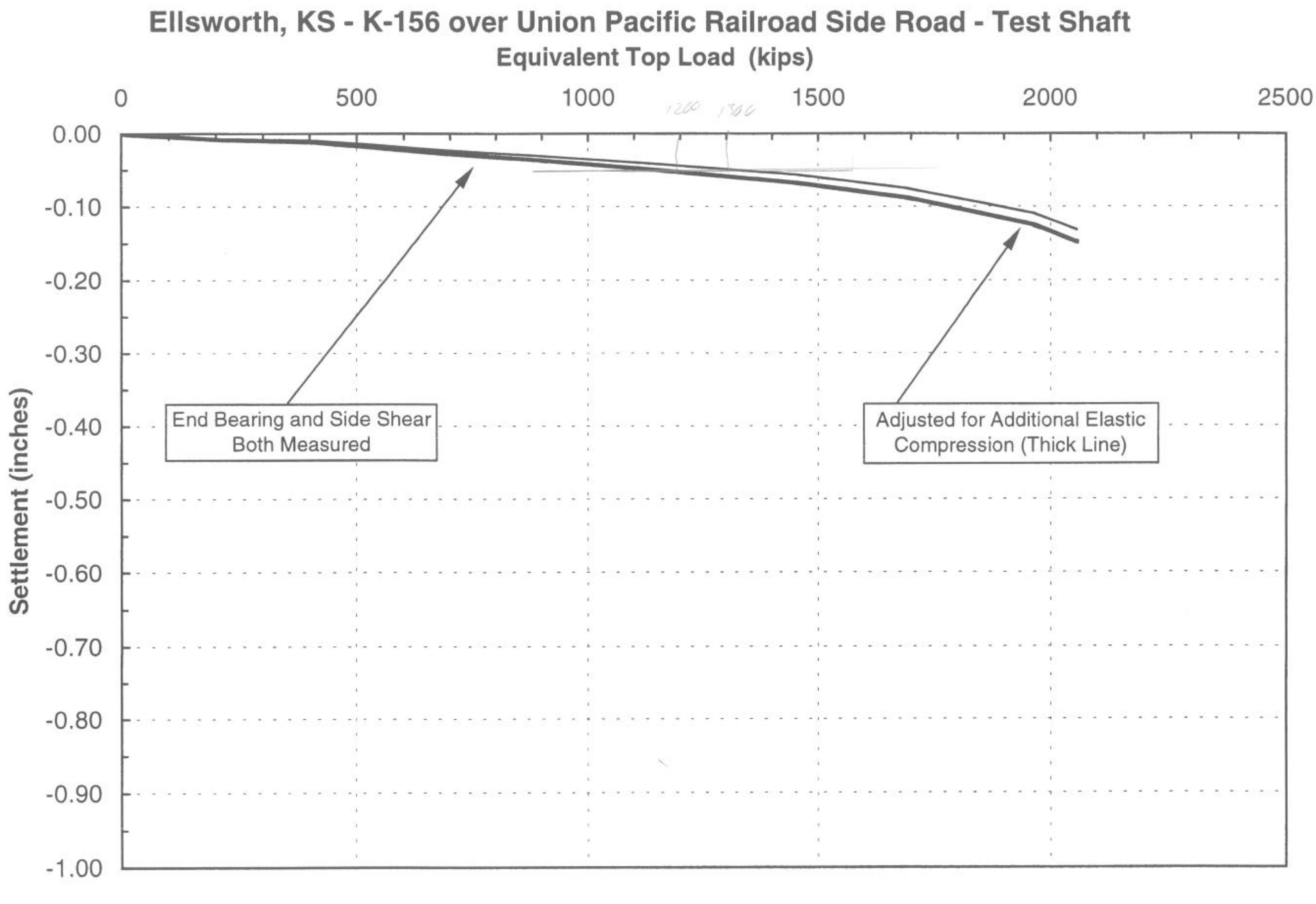

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Figure 2 of 5

Strain Gage Load Distribution Curves

Ellsworth, KS - K-156 over Union Pacific Railroad Side Road - Test Shaft

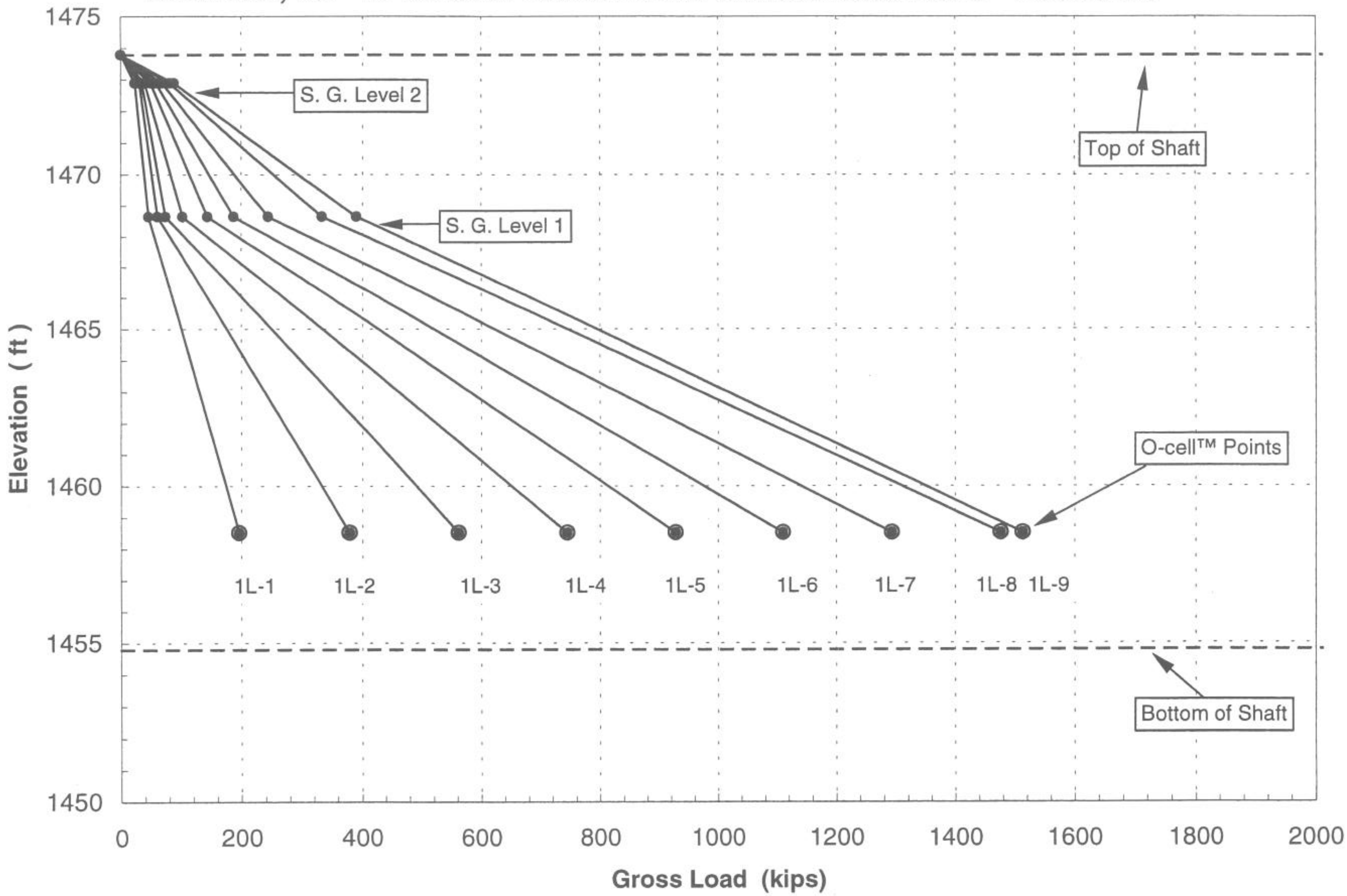

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Figure 3 of 5

Side Shear Creep Limit

Ellsworth, KS - K-156 over Union Pacific Railroad Side Road - Test Shaft

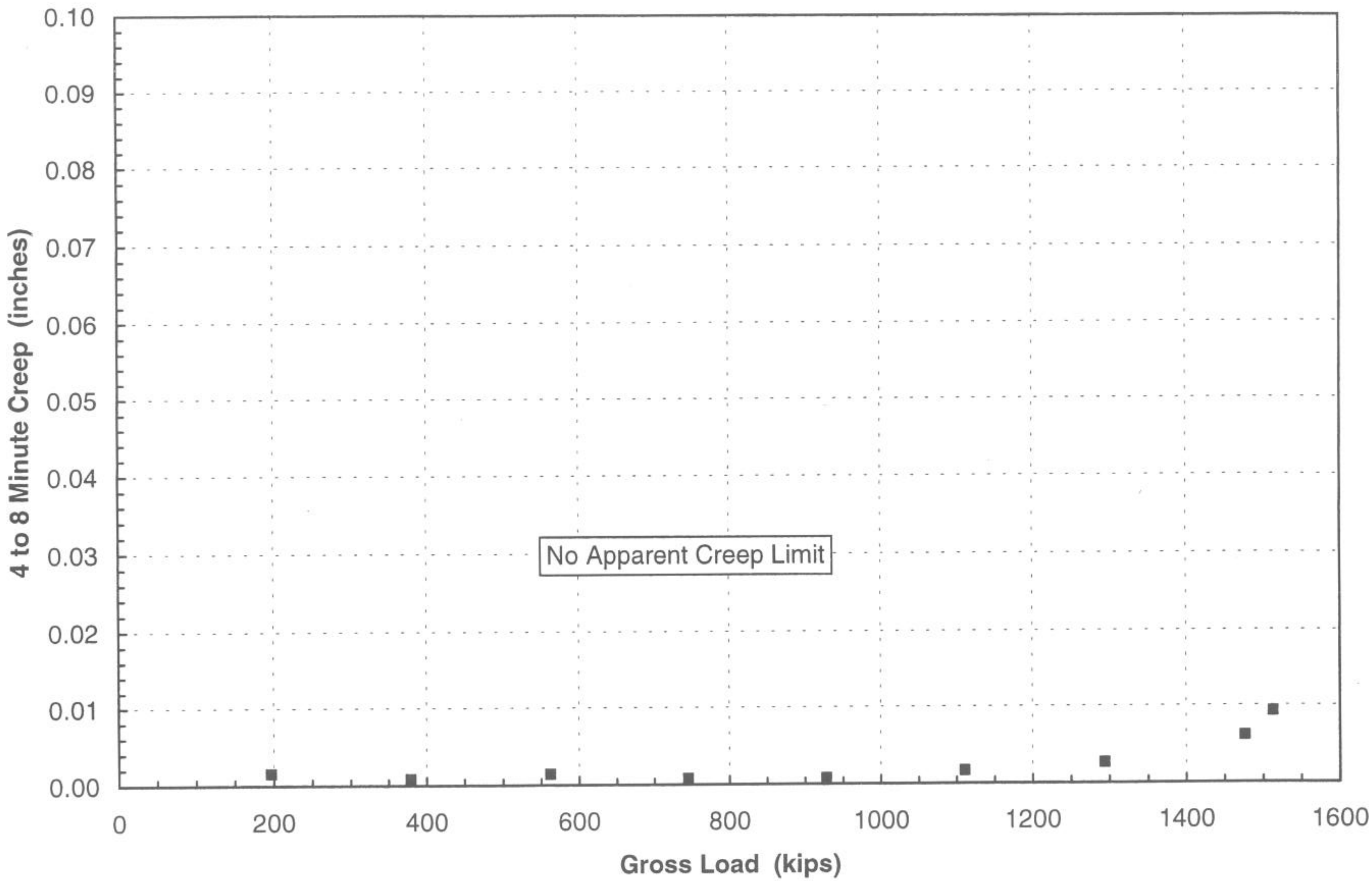

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Figure 4 of 5

End Bearing Creep Limit

Ellsworth, KS - K-156 over Union Pacific Railroad Side Road - Test Shaft

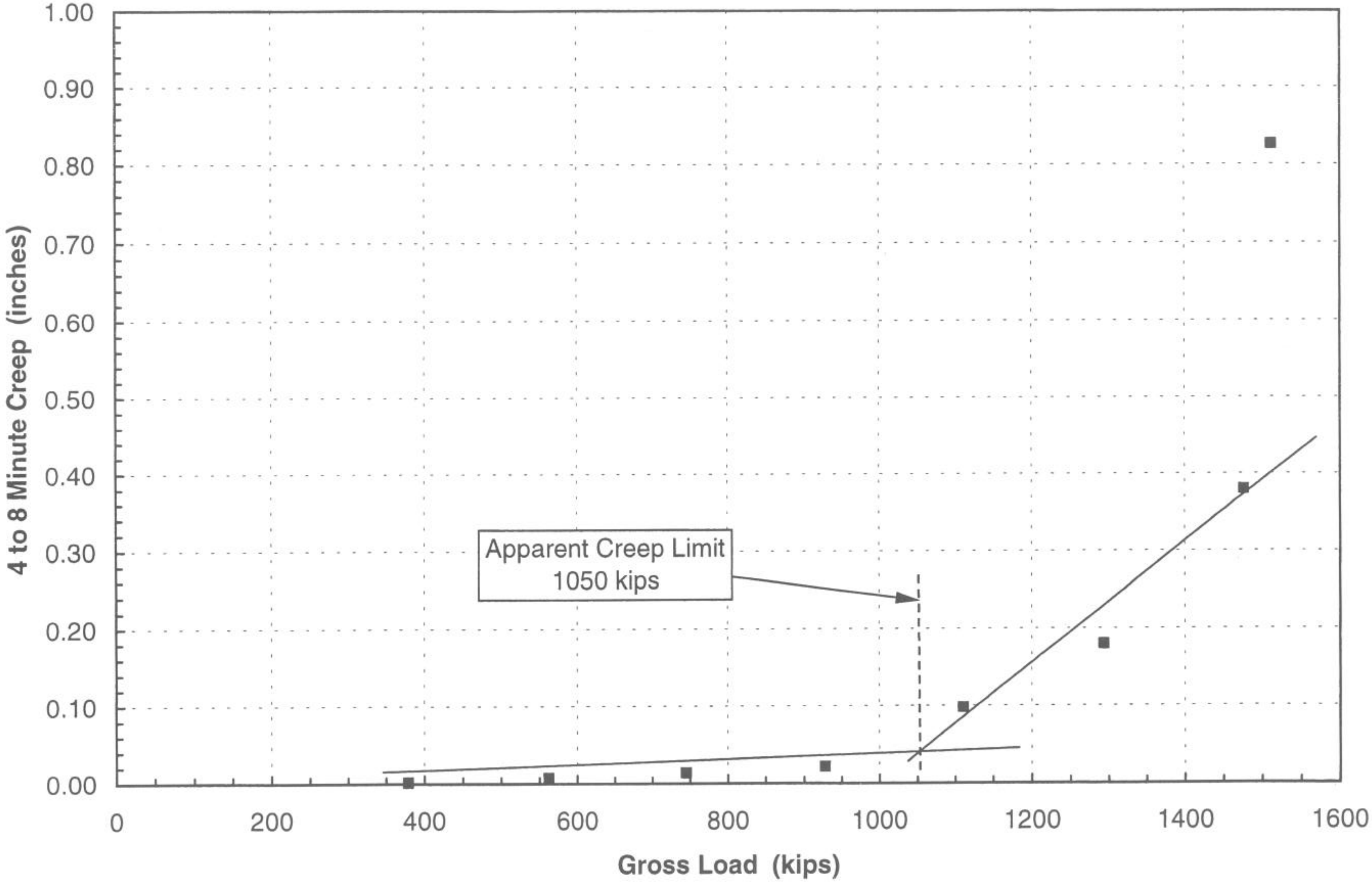

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Figure 5 of 5

APPENDIX A

FIELD DATA & DATA REDUCTION

Gross and Net O-cell™ Loads

Ellsworth, KS - K-156 over Union Pacific Railroad & Side Road - Test Shaft

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell™ Pressure (psi)	Gross O-cell™ Load Pos. A1 (kips)	Gross Load Pressure (kips)	Net Load Pressure (kips)
1L -0	14:10:00	0	0	0	0	0
1L -1	14:19:30	1	500	196	196	182
1L -1	14:20:30	2	500	196	196	182
1L -1	14:22:30	4	500	196	196	182
1L -1	14:26:30	8	500	196	196	182
1L -2	14:28:00	1	1000	379	379	365
1L -2	14:29:00	2	1000	379	379	365
1L -2	14:31:00	4	1000	379	379	365
1L -2	14:35:00	8	1000	379	379	365
1L -3	14:37:30	1	1500	562	562	548
1L -3	14:38:30	2	1500	562	562	548
1L -3	14:40:30	4	1500	562	562	548
1L -3	14:44:30	8	1500	562	562	548
1L -4	14:53:00	1	2000	745	745	731
1L -4	14:54:00	2	2000	745	745	731
1L -4	14:56:00	4	2000	745	745	731
1L -4	15:00:00	8	2000	745	745	731
1L -5	15:02:00	1	2500	928	928	914
1L -5	15:03:00	2	2500	928	928	914
1L -5	15:05:00	4	2500	928	928	914
1L -5	15:09:00	8	2500	928	928	914
1L -6	15:11:00	1	3000	1111	1111	1097
1L -6	15:12:00	2	3000	1111	1111	1097
1L -6	15:14:00	4	3000	1111	1111	1097
1L -6	15:18:00	8	3000	1111	1111	1097
1L -7	15:22:30	1	3500	1294	1294	1280
1L -7	15:23:30	2	3500	1294	1294	1280
1L -7	15:25:30	4	3500	1294	1294	1280
1L -7	15:29:30	8	3500	1294	1294	1280
1L -8	15:37:00	1	4000	1477	1477	1462
1L -8	15:38:00	2	4000	1477	1477	1462
1L -8	15:40:00	4	4000	1477	1477	1462
1L -8	15:44:00	8	4000	1477	1477	1462
1L -9	15:47:00	1	4100	1513	1513	1499
1L -9	15:48:00	2	4100	1513	1513	1499
1L -9	15:50:00	4	4100	1513	1513	1499
1L -9	15:54:00	8	4100	1513	1513	1499
1U -1	16:01:00	1	2600	964	964	950
1U -1	16:02:00	2	2600	964	964	950
1U -1	16:03:00	3	2600	964	964	950
1U -1	16:04:00	4	2600	964	964	950
1U -2	16:06:00	1	1300	489	489	475
1U -2	16:07:00	2	1300	489	489	475
1U -2	16:08:00	3	1300	489	489	475
1U -2	16:09:00	4	1300	489	489	475
1U -3	16:11:00	1	650	251	251	237
1U -3	16:12:00	2	650	251	251	237
1U -3	16:13:00	3	650	251	251	237
1U -3	16:14:00	4	650	251	251	237
1U -4	16:16:00	1	0	0	0	0
1U -4	16:17:00	2	0	0	0	0
1U -4	16:19:00	4	0	0	0	0
1U -4	16:23:00	8	0	0	0	0

Top of Shaft, Compression and Reference Beam Movement
Ellsworth, KS - K-156 over Union Pacific Railroad & Side Road - Test Shaft

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell™ Pressure (psi)	Applied Load (kips)	TOS Indicator Readings			Telltale Compression		
					Side A (inches)	Side B (inches)	Average (inches)	Side A (inches)	Side B (inches)	Average (inches)
1L -0	14:10:00	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000
1L -1	14:19:30	1	500	196	0.004	0.004	0.004	0.003	0.001	0.002
1L -1	14:20:30	2	500	196	0.005	0.005	0.005	0.003	0.001	0.002
1L -1	14:22:30	4	500	196	0.004	0.004	0.004	0.003	0.001	0.002
1L -1	14:26:30	8	500	196	0.006	0.005	0.005	0.003	0.001	0.002
1L -2	14:28:00	1	1,000	379	0.006	0.005	0.006	0.003	0.001	0.002
1L -2	14:29:00	2	1,000	379	0.007	0.008	0.007	0.003	0.001	0.002
1L -2	14:31:00	4	1,000	379	0.007	0.007	0.007	0.003	0.001	0.002
1L -2	14:35:00	8	1,000	379	0.008	0.007	0.008	0.003	0.001	0.002
1L -3	14:37:30	1	1,500	562	0.015	0.015	0.015	0.003	0.004	0.004
1L -3	14:38:30	2	1,500	562	0.017	0.017	0.017	0.003	0.004	0.004
1L -3	14:40:30	4	1,500	562	0.017	0.016	0.017	0.003	0.004	0.004
1L -3	14:44:30	8	1,500	562	0.018	0.018	0.018	0.003	0.004	0.004
1L -4	14:53:00	1	2,000	745	0.023	0.023	0.023	0.003	0.007	0.005
1L -4	14:54:00	2	2,000	745	0.024	0.024	0.024	0.003	0.007	0.005
1L -4	14:56:00	4	2,000	745	0.025	0.025	0.025	0.003	0.007	0.005
1L -4	15:00:00	8	2,000	745	0.025	0.027	0.026	0.003	0.007	0.005
1L -5	15:02:00	1	2,500	928	0.033	0.034	0.033	0.004	0.009	0.006
1L -5	15:03:00	2	2,500	928	0.035	0.035	0.035	0.004	0.009	0.006
1L -5	15:05:00	4	2,500	928	0.036	0.035	0.035	0.004	0.009	0.006
1L -5	15:09:00	8	2,500	928	0.035	0.037	0.036	0.004	0.009	0.007
1L -6	15:11:00	1	3,000	1,111	0.043	0.046	0.044	0.006	0.009	0.008
1L -6	15:12:00	2	3,000	1,111	0.047	0.046	0.046	0.007	0.009	0.008
1L -6	15:14:00	4	3,000	1,111	0.046	0.049	0.047	0.007	0.009	0.008
1L -6	15:18:00	8	3,000	1,111	0.047	0.051	0.049	0.007	0.009	0.008
1L -7	15:22:30	1	3,500	1,294	0.060	0.062	0.061	0.008	0.010	0.009
1L -7	15:23:30	2	3,500	1,294	0.062	0.061	0.061	0.008	0.010	0.009
1L -7	15:25:30	4	3,500	1,294	0.062	0.065	0.063	0.008	0.010	0.009
1L -7	15:29:30	8	3,500	1,294	0.064	0.067	0.066	0.008	0.011	0.009
1L -8	15:37:00	1	4,000	1,477	0.085	0.088	0.087	0.010	0.014	0.012
1L -8	15:38:00	2	4,000	1,477	0.088	0.089	0.088	0.010	0.014	0.012
1L -8	15:40:00	4	4,000	1,477	0.091	0.091	0.091	0.010	0.014	0.012
1L -8	15:44:00	8	4,000	1,477	0.096	0.097	0.096	0.011	0.015	0.013
1L -9	15:47:00	1	4,100	1,513	0.101	0.103	0.102	0.011	0.015	0.013
1L -9	15:48:00	2	4,100	1,513	0.104	0.105	0.105	0.012	0.015	0.013
1L -9	15:50:00	4	4,100	1,513	0.108	0.110	0.109	0.012	0.015	0.013
1L -9	15:54:00	8	4,100	1,513	0.115	0.119	0.117	0.014	0.015	0.015
1U -1	16:01:00	1	2,600	964	0.113	0.115	0.114	0.012	0.015	0.014
1U -1	16:02:00	2	2,600	964	0.112	0.115	0.114	0.012	0.015	0.013
1U -1	16:03:00	3	2,600	964	0.113	0.116	0.114	0.012	0.015	0.013
1U -1	16:04:00	4	2,600	964	0.112	0.115	0.113	0.012	0.015	0.013
1U -2	16:06:00	1	1,300	489	0.106	0.109	0.108	0.009	0.008	0.009
1U -2	16:07:00	2	1,300	489	0.106	0.109	0.107	0.009	0.008	0.008
1U -2	16:08:00	3	1,300	489	0.105	0.108	0.107	0.009	0.008	0.008
1U -2	16:09:00	4	1,300	489	0.104	0.108	0.106	0.009	0.007	0.008
1U -3	16:11:00	1	650	251	0.100	0.103	0.101	0.008	0.004	0.006
1U -3	16:12:00	2	650	251	0.099	0.103	0.101	0.007	0.003	0.005
1U -3	16:13:00	3	650	251	0.098	0.101	0.100	0.007	0.003	0.005
1U -3	16:14:00	4	650	251	0.098	0.101	0.100	0.007	0.002	0.005
1U -4	16:16:00	1	0	0	0.086	0.088	0.087	0.006	-0.003	0.002
1U -4	16:17:00	2	0	0	0.084	0.086	0.085	0.006	-0.003	0.002
1U -4	16:19:00	4	0	0	0.082	0.085	0.084	0.004	-0.003	0.001
1U -4	16:23:00	8	0	0	0.082	0.085	0.084	0.004	-0.003	0.001

O-cell™ Expansion and Upward and Downward Movement
Ellsworth, KS - K-156 over Union Pacific Railroad & Side Road - Test Shaft

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell™ Pressure (psi)	Applied Load (kips)	LVWDT Readings (Expansion) 18567 (inches)	18568 (inches)	18569 (inches)	Average (inches)	Upward Movement (inches)	Upward Creep (inches)	Downward Movement (inches)	Downward Creep (inches)
1L -0	14:10:00	0	0	0	0.000	0.000	-0.001	0.000	0.000		0.000	
1L -1	14:19:30	1	500	196	0.040	0.040	0.053	0.040	0.006		-0.034	
1L -1	14:20:30	2	500	196	0.040	0.040	0.053	0.040	0.006		-0.034	
1L -1	14:22:30	4	500	196	0.040	0.041	0.054	0.040	0.005		-0.035	
1L -1	14:26:30	8	500	196	0.040	0.040	0.054	0.040	0.007	0.002	-0.033	-0.002
1L -2	14:28:00	1	1,000	379	0.061	0.058	0.077	0.060	0.008		-0.052	
1L -2	14:29:00	2	1,000	379	0.065	0.062	0.080	0.063	0.009		-0.054	
1L -2	14:31:00	4	1,000	379	0.066	0.063	0.082	0.065	0.009		-0.056	
1L -2	14:35:00	8	1,000	379	0.069	0.066	0.085	0.067	0.010	0.001	-0.058	0.002
1L -3	14:37:30	1	1,500	562	0.127	0.126	0.150	0.126	0.019		-0.108	
1L -3	14:38:30	2	1,500	562	0.133	0.135	0.156	0.134	0.020		-0.113	
1L -3	14:40:30	4	1,500	562	0.139	0.140	0.162	0.139	0.020		-0.119	
1L -3	14:44:30	8	1,500	562	0.147	0.148	0.170	0.148	0.022	0.001	-0.126	0.007
1L -4	14:53:00	1	2,000	745	0.215	0.216	0.243	0.215	0.028		-0.188	
1L -4	14:54:00	2	2,000	745	0.226	0.228	0.255	0.227	0.029		-0.198	
1L -4	14:56:00	4	2,000	745	0.242	0.243	0.270	0.242	0.030		-0.213	
1L -4	15:00:00	8	2,000	745	0.260	0.254	0.280	0.257	0.031	0.001	-0.226	0.014
1L -5	15:02:00	1	2,500	928	0.345	0.344	0.377	0.344	0.040		-0.304	
1L -5	15:03:00	2	2,500	928	0.356	0.354	0.388	0.355	0.041		-0.314	
1L -5	15:05:00	4	2,500	928	0.373	0.370	0.404	0.372	0.042		-0.330	
1L -5	15:09:00	8	2,500	928	0.396	0.393	0.427	0.395	0.043	0.001	-0.352	0.022
1L -6	15:11:00	1	3,000	1,111	0.517	0.512	0.550	0.515	0.052		-0.463	
1L -6	15:12:00	2	3,000	1,111	0.556	0.549	0.589	0.552	0.054		-0.499	
1L -6	15:14:00	4	3,000	1,111	0.597	0.586	0.625	0.592	0.055		-0.536	
1L -6	15:18:00	8	3,000	1,111	0.698	0.686	0.724	0.692	0.057	0.002	-0.635	0.098
1L -7	15:22:30	1	3,500	1,294	1.329	1.311	1.366	1.320	0.069		-1.251	
1L -7	15:23:30	2	3,500	1,294	1.394	1.377	1.433	1.386	0.070		-1.316	
1L -7	15:25:30	4	3,500	1,294	1.509	1.491	1.548	1.500	0.072		-1.427	
1L -7	15:29:30	8	3,500	1,294	1.690	1.675	1.732	1.683	0.075	0.003	-1.607	0.180
1L -8	15:37:00	1	4,000	1,477	2.923	2.902	3.003	2.913	0.099		-2.814	
1L -8	15:38:00	2	4,000	1,477	3.050	3.030	3.137	3.040	0.100		-2.939	
1L -8	15:40:00	4	4,000	1,477	3.309	3.285	3.409	3.297	0.103		-3.194	
1L -8	15:44:00	8	4,000	1,477	3.696	3.670	3.812	3.683	0.109	0.006	-3.574	0.380
1L -9	15:47:00	1	4,100	1,513	4.174	4.148	4.317	4.161	0.115		-4.046	
1L -9	15:48:00	2	4,100	1,513	4.380	4.355	4.537	4.368	0.118		-4.250	
1L -9	15:50:00	4	4,100	1,513	4.793	4.769	4.981	4.781	0.122		-4.659	
1L -9	15:54:00	8	4,100	1,513	5.628	5.605	5.877	5.617	0.132	0.009	-5.485	0.826
1U -1	16:01:00	1	2,600	964	5.678	5.652	5.948	5.665	0.128		-5.538	
1U -1	16:02:00	2	2,600	964	5.676	5.651	5.947	5.664	0.127		-5.536	
1U -1	16:03:00	3	2,600	964	5.678	5.652	5.949	5.665	0.128		-5.537	
1U -1	16:04:00	4	2,600	964	5.677	5.649	5.950	5.663	0.127		-5.536	
1U -2	16:06:00	1	1,300	489	5.493	5.465	5.749	5.479	0.116		-5.363	
1U -2	16:07:00	2	1,300	489	5.485	5.458	5.746	5.472	0.116		-5.356	
1U -2	16:08:00	3	1,300	489	5.481	5.453	5.737	5.467	0.115		-5.352	
1U -2	16:09:00	4	1,300	489	5.480	5.453	5.739	5.467	0.115		-5.352	
1U -3	16:11:00	1	650	251	5.281	5.251	5.522	5.266	0.107		-5.159	
1U -3	16:12:00	2	650	251	5.264	5.233	5.502	5.248	0.106		-5.143	
1U -3	16:13:00	3	650	251	5.254	5.223	5.492	5.239	0.105		-5.134	
1U -3	16:14:00	4	650	251	5.247	5.215	5.484	5.231	0.105		-5.126	
1U -4	16:16:00	1	0	0	4.904	4.863	5.101	4.883	0.089		-4.795	
1U -4	16:17:00	2	0	0	4.886	4.846	5.082	4.866	0.086		-4.779	
1U -4	16:19:00	4	0	0	4.868	4.826	5.066	4.847	0.084		-4.762	
1U -4	16:23:00	8	0	0	4.848	4.808	5.042	4.828	0.084		-4.744	

O-cell™ Expansion and Upward and Downward Movement
Ellsworth, KS - K-156 over Union Pacific Railroad & Side Road - Test Shaft

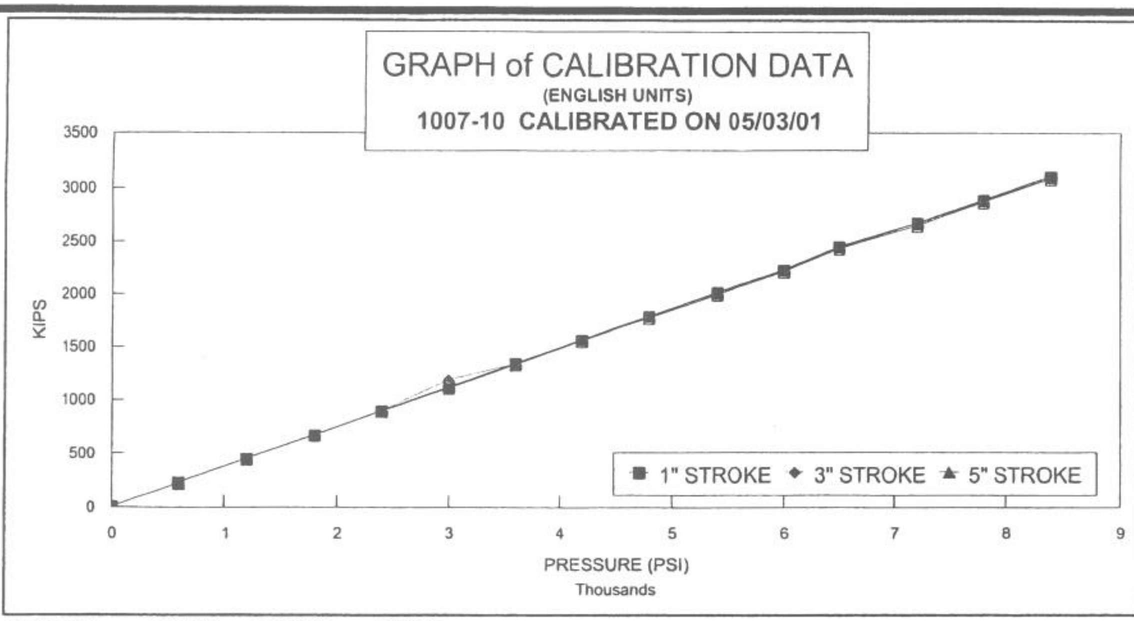
Load	Time	Time After	O-cell™	Applied	LVWDT Readings (Expansion)				Upward *	Upward	Downward	Downward
Test		Start	Pressure	Load	18567	18568	18569	Average	Movement	Creep	Movement	Creep
Increment	(h:m:s)	Minutes	(psi)	(kips)	(inches)	(inches)	(inches)	(inches)	(inches)	(inches)	(inches)	(inches)
1L -0	14:10:00	0	0	0	0.000	0.000	-0.001	0.000	0.000		0.000	
1L -1	14:19:30	1	500	196	0.040	0.040	0.053	0.040	0.006		-0.034	
1L -1	14:20:30	2	500	196	0.040	0.040	0.053	0.040	0.006		-0.034	
1L -1	14:22:30	4	500	196	0.040	0.041	0.054	0.040	0.005		-0.035	
1L -1	14:26:30	8	500	196	0.040	0.040	0.054	0.040	0.007	0.002	-0.033	-0.002
1L -2	14:28:00	1	1,000	379	0.061	0.058	0.077	0.060	0.008		-0.052	
1L -2	14:29:00	2	1,000	379	0.065	0.062	0.080	0.063	0.009		-0.054	
1L -2	14:31:00	4	1,000	379	0.066	0.063	0.082	0.065	0.009		-0.056	
1L -2	14:35:00	8	1,000	379	0.069	0.066	0.085	0.067	0.010	0.001	-0.058	0.002
1L -3	14:37:30	1	1,500	562	0.127	0.126	0.150	0.126	0.019		-0.108	
1L -3	14:38:30	2	1,500	562	0.133	0.135	0.156	0.134	0.020		-0.113	
1L -3	14:40:30	4	1,500	562	0.139	0.140	0.162	0.139	0.020		-0.119	
1L -3	14:44:30	8	1,500	562	0.147	0.148	0.170	0.148	0.022	0.001	-0.126	0.007
1L -4	14:53:00	1	2,000	745	0.215	0.216	0.243	0.215	0.028		-0.188	
1L -4	14:54:00	2	2,000	745	0.226	0.228	0.255	0.227	0.029		-0.198	
1L -4	14:56:00	4	2,000	745	0.242	0.243	0.270	0.242	0.030		-0.213	
1L -4	15:00:00	8	2,000	745	0.260	0.254	0.280	0.257	0.031	0.001	-0.226	0.014
1L -5	15:02:00	1	2,500	928	0.345	0.344	0.377	0.344	0.040		-0.304	
1L -5	15:03:00	2	2,500	928	0.356	0.354	0.388	0.355	0.041		-0.314	
1L -5	15:05:00	4	2,500	928	0.373	0.370	0.404	0.372	0.042		-0.330	
1L -5	15:09:00	8	2,500	928	0.396	0.393	0.427	0.395	0.043	0.001	-0.352	0.022
1L -6	15:11:00	1	3,000	1,111	0.517	0.512	0.550	0.515	0.052		-0.463	
1L -6	15:12:00	2	3,000	1,111	0.556	0.549	0.589	0.552	0.054		-0.499	
1L -6	15:14:00	4	3,000	1,111	0.597	0.586	0.625	0.592	0.055		-0.536	
1L -6	15:18:00	8	3,000	1,111	0.698	0.686	0.724	0.692	0.057	0.002	-0.635	0.098
1L -7	15:22:30	1	3,500	1,294	1.329	1.311	1.366	1.320	0.069		-1.251	
1L -7	15:23:30	2	3,500	1,294	1.394	1.377	1.433	1.386	0.070		-1.316	
1L -7	15:25:30	4	3,500	1,294	1.509	1.491	1.548	1.500	0.072		-1.427	
1L -7	15:29:30	8	3,500	1,294	1.690	1.675	1.732	1.683	0.075	0.003	-1.607	0.180
1L -8	15:37:00	1	4,000	1,477	2.923	2.902	3.003	2.913	0.099		-2.814	
1L -8	15:38:00	2	4,000	1,477	3.050	3.030	3.137	3.040	0.100		-2.939	
1L -8	15:40:00	4	4,000	1,477	3.309	3.285	3.409	3.297	0.103		-3.194	
1L -8	15:44:00	8	4,000	1,477	3.696	3.670	3.812	3.683	0.109	0.006	-3.574	0.380
1L -9	15:47:00	1	4,100	1,513	4.174	4.148	4.317	4.161	0.115		-4.046	
1L -9	15:48:00	2	4,100	1,513	4.380	4.355	4.537	4.368	0.118		-4.250	
1L -9	15:50:00	4	4,100	1,513	4.793	4.769	4.981	4.781	0.122		-4.659	
1L -9	15:54:00	8	4,100	1,513	5.628	5.605	5.877	5.617	0.132	0.009	-5.485	0.826
1U -1	16:01:00	1	2,600	964	5.678	5.652	5.948	5.665	0.128		-5.538	
1U -1	16:02:00	2	2,600	964	5.676	5.651	5.947	5.664	0.127		-5.536	
1U -1	16:03:00	3	2,600	964	5.678	5.652	5.949	5.665	0.128		-5.537	
1U -1	16:04:00	4	2,600	964	5.677	5.649	5.950	5.663	0.127		-5.536	
1U -2	16:06:00	1	1,300	489	5.493	5.465	5.749	5.479	0.116		-5.363	
1U -2	16:07:00	2	1,300	489	5.485	5.458	5.746	5.472	0.116		-5.356	
1U -2	16:08:00	3	1,300	489	5.481	5.453	5.737	5.467	0.115		-5.352	
1U -2	16:09:00	4	1,300	489	5.480	5.453	5.739	5.467	0.115		-5.352	
1U -3	16:11:00	1	650	251	5.281	5.251	5.522	5.266	0.107		-5.159	
1U -3	16:12:00	2	650	251	5.264	5.233	5.502	5.248	0.106		-5.143	
1U -3	16:13:00	3	650	251	5.254	5.223	5.492	5.239	0.105		-5.134	
1U -3	16:14:00	4	650	251	5.247	5.215	5.484	5.231	0.105		-5.126	
1U -4	16:16:00	1	0	0	4.904	4.863	5.101	4.883	0.089		-4.795	
1U -4	16:17:00	2	0	0	4.886	4.846	5.082	4.866	0.086		-4.779	
1U -4	16:19:00	4	0	0	4.868	4.826	5.066	4.847	0.084		-4.762	
1U -4	16:23:00	8	0	0	4.848	4.808	5.042	4.828	0.084		-4.744	

Strain Gage Readings and Loads at Levels 1 and 2
Ellsworth, KS - K-156 over Union Pacific Railroad & Side Road - Test Shaft

Load Test Increment	Time 0 (h:m:s)	Time After Start Minutes	O-cell™ Pressure (psi)	Applied Load (kips)	Level 1 21306 με	Level 1 21305 με	Level 1 Av. Load (kips)	Level 2 21307 με	Level 2 21308 με	Level 2 Av. Load (kips)
1L -0	14:10:00	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
1L -1	14:19:30	1	500	196	12.4	4.3	45.7	2.8	5.8	23.5
1L -1	14:20:30	2	500	196	12.7	4.2	46.4	2.8	5.8	23.5
1L -1	14:22:30	4	500	196	12.5	4.2	45.4	2.9	5.7	23.4
1L -1	14:26:30	8	500	196	12.8	4.0	46.0	2.9	5.6	23.3
1L -2	14:28:00	1	1,000	379	16.1	5.3	58.6	3.4	7.4	29.5
1L -2	14:29:00	2	1,000	379	16.4	5.3	59.5	3.7	7.5	30.5
1L -2	14:31:00	4	1,000	379	16.5	5.3	59.6	3.5	7.5	30.3
1L -2	14:35:00	8	1,000	379	17.0	5.3	60.9	3.5	7.7	30.6
1L -3	14:37:30	1	1,500	562	19.9	6.0	70.6	3.7	8.6	33.6
1L -3	14:38:30	2	1,500	562	20.3	6.2	72.5	3.9	8.8	34.7
1L -3	14:40:30	4	1,500	562	20.2	6.4	72.6	3.9	8.9	34.9
1L -3	14:44:30	8	1,500	562	20.4	6.6	74.0	3.9	9.0	35.2
1L -4	14:53:00	1	2,000	745	25.7	9.8	97.0	3.5	10.5	38.1
1L -4	14:54:00	2	2,000	745	26.1	10.2	99.3	3.5	10.6	38.4
1L -4	14:56:00	4	2,000	745	26.5	10.4	101.0	3.4	10.8	38.8
1L -4	15:00:00	8	2,000	745	26.8	10.7	102.4	3.3	11.3	39.9
1L -5	15:02:00	1	2,500	928	35.3	14.6	136.3	3.1	14.5	48.2
1L -5	15:03:00	2	2,500	928	35.8	14.7	138.1	3.0	14.6	48.1
1L -5	15:05:00	4	2,500	928	36.7	14.8	140.7	3.1	14.7	48.7
1L -5	15:09:00	8	2,500	928	37.3	15.4	143.8	3.2	14.9	49.4
1L -6	15:11:00	1	3,000	1,111	45.6	19.1	176.9	3.5	16.9	55.8
1L -6	15:12:00	2	3,000	1,111	46.5	19.6	180.5	3.5	17.0	56.1
1L -6	15:14:00	4	3,000	1,111	47.0	20.2	183.6	3.6	17.3	57.3
1L -6	15:18:00	8	3,000	1,111	47.7	20.9	187.3	3.7	17.6	58.3
1L -7	15:22:30	1	3,500	1,294	57.3	27.1	230.6	4.1	20.0	65.7
1L -7	15:23:30	2	3,500	1,294	57.9	27.5	233.3	4.2	20.1	66.2
1L -7	15:25:30	4	3,500	1,294	58.6	28.2	237.3	4.1	20.4	66.8
1L -7	15:29:30	8	3,500	1,294	60.0	29.4	244.3	4.3	20.7	68.3
1L -8	15:37:00	1	4,000	1,477	74.6	39.1	310.7	4.8	23.6	77.5
1L -8	15:38:00	2	4,000	1,477	75.1	39.4	313.1	4.9	23.6	77.8
1L -8	15:40:00	4	4,000	1,477	78.2	41.0	325.6	4.9	24.2	79.4
1L -8	15:44:00	8	4,000	1,477	79.9	41.9	332.8	4.9	24.6	80.7
1L -9	15:47:00	1	4,100	1,513	84.1	44.9	352.6	5.1	25.4	83.4
1L -9	15:48:00	2	4,100	1,513	86.1	46.1	361.2	5.3	25.9	85.3
1L -9	15:50:00	4	4,100	1,513	89.0	47.1	371.9	5.3	26.3	86.3
1L -9	15:54:00	8	4,100	1,513	93.5	49.3	390.1	5.3	26.9	88.1
1U -1	16:01:00	1	2,600	964	81.1	36.4	320.9	3.0	21.6	67.1
1U -1	16:02:00	2	2,600	964	80.1	35.4	315.7	2.9	21.0	65.4
1U -1	16:03:00	3	2,600	964	79.8	35.2	321.7	20.8	0.5	58.1
1U -1	16:04:00	4	2,600	964	79.7	35.0	313.5	2.8	20.9	64.9
1U -2	16:06:00	1	1,300	489	60.3	16.7	210.3	1.4	12.8	39.0
1U -2	16:07:00	2	1,300	489	59.7	16.0	206.8	1.5	12.5	38.2
1U -2	16:08:00	3	1,300	489	59.1	15.6	207.4	12.1	0.5	34.3
1U -2	16:09:00	4	1,300	489	59.0	15.5	203.6	1.3	12.4	37.4
1U -3	16:11:00	1	650	251	45.6	3.1	133.2	1.3	7.5	24.0
1U -3	16:12:00	2	650	251	44.9	2.2	128.8	1.3	7.1	22.8
1U -3	16:13:00	3	650	251	44.2	2.1	129.8	6.8	0.5	19.7
1U -3	16:14:00	4	650	251	43.8	1.6	124.3	1.4	6.7	22.0
1U -4	16:16:00	1	0	0	30.9	-7.7	63.3	2.8	3.7	17.8
1U -4	16:17:00	2	0	0	30.5	-8.1	61.2	3.0	3.7	18.4
1U -4	16:19:00	4	0	0	29.8	-8.3	58.9	3.0	3.7	18.3
1U -4	16:23:00	8	0	0	29.7	-8.4	58.3	3.2	3.7	19.0

APPENDIX B

CALIBRATION OF O-CELLS
STRAIN GAGES AND LVWDTs



STROKE:	1 INCH	3 INCH	5 INCH
PRESSURE PSI	LOAD KIPS	LOAD KIPS	LOAD KIPS
0	0	0	0
600	224	223	223
1200	445	445	442
1800	667	668	663
2400	893	890	886
3000	1114	1185	1102
3600	1336	1332	1323
4200	1557	1550	1544
4800	1778	1770	1760
5400	2002	1990	1980
6000	2214	2206	2195
6500	2436	2424	2414
7200	2652	2644	2629
7800	2867	2855	2844
8400	3083	3069	3059

26" O-CELL, SERIAL # 1007-10

LOAD CONVERSION FORMULA

LOAD = PRESSURE * 0.3658 + (13.3)

{KIPS} {PSI}

Regression Output:

Constant	13.319
X Coefficient	0.366
R Squared	1.000
No. of Observations	42
Degrees of Freedom	40
Std Err of Y Est	17.853
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: MIDWEST FOUNDATIONS
*AE & FC JOB NO.: 2293	*JOB LOCATION: TOPEKA, KS
*CUSTOMER P.O.NO.: LT-8790	*DATED: 07/31/01

SERVICE ENGINEER: [signature] DATE: 8/3/01

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

Vibrating Wire Displacement Transducer Calibration Report

Model Number: 4450-3-6

Range: 6"

Serial Number: 18567

Mfg. Number: 01-640

Customer: Loadtest Inc.

Temperature: 24.2 °C

Cust. I.D. #: n/a

Cal. Std. Control #(s): 124, 213, 370, 506, 524

Job Number: 17419

Date of Calibration: June 13, 2001

Technician: CMB

Displacement (inches)	GK-401 Reading Position B Cycle 1	Cycle 2	Average	Change	% Linearity
0.000	2413	2413	2413		-0.24
1.200	3663	3661	3662	1249	0.09
2.400	4897	4895	4896	1234	0.18
3.600	6123	6121	6122	1226	0.14
4.800	7341	7341	7341	1219	-0.02
6.000	8561	8560	8561	1220	-0.17

Calibration Factor (C): 0.0009767 (Inches/Digit)

Regression Zero: 2428

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B":* 5541

or

Position "F":*

Date: August 7, 2001

Temperature: 24.2 °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: 18568

Mfg. Number: 01-641

Customer: Loadtest Inc.

Temperature: 24.2 °C

Cust. I.D. #: n/a

Cal. Std. Control #(s): 124, 213, 370, 506, 524

Job Number: 17419

Date of Calibration: June 13, 2001

Technician: CMB

Displacement (inches)	GK-401 Reading Position B Cycle 1	Cycle 2	Average	Change	% Linearity
0.000	2359	2357	2358		-0.25
1.200	3635	3635	3635	1277	0.09
2.400	4900	4894	4897	1262	0.20
3.600	6151	6147	6149	1252	0.15
4.800	7392	7394	7393	1244	-0.02
6.000	8639	8638	8639	1246	-0.18

Calibration Factor (C): 0.0009561 (Inches/Digit)

Regression Zero: 2374

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B":* 5550

or

Position "F":*

Date: August 7, 2001

Temperature: 23.3 °C

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

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

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

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

Vibrating Wire Displacement Transducer Calibration Report

Model Number:	4450-3-6	Range:	6"
Serial Number:	18569	Mfg. Number:	01-642
Customer:	Loadtest Inc.	Temperature:	24.2 °C
Cust. I.D. #:	n/a	Cal. Std. Control #(s):	124, 213, 370, 506, 524
Job Number:	17419	Date of Calibration:	June 13, 2001

Technician: CMB

Displacement (inches)	GK-401 Reading Position B Cycle 1	Cycle 2	Average	Change	% Linearity
0.000	2444	2443	2444		-0.19
1.200	3690	3690	3690	1247	0.06
2.400	4926	4926	4926	1236	0.15
3.600	6155	6156	6156	1230	0.12
4.800	7378	7379	7379	1223	-0.01
6.000	8601	8601	8601	1223	-0.14

Calibration Factor (C): 0.0009749 (Inches/Digit)

Regression Zero: 2455

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B":* 5572 Date: August 7, 2001

or

Position "F":* ______ Temperature: 23.8 °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: 4450-3-1

Range: 1"

Serial Number: 18570

Mfg. Number: 01-681

Customer: Loadtest Inc.

Temperature: 25.2 °C

Cust. I.D. #: n/a

Cal. Std. Control #(s): 213, 338, 506, 524, 529

Job Number: 17419

Date of Calibration: July 17, 2001

Technician: CMB

Displacement (inches)	GK-401 Reading Position B Cycle 1	Cycle 2	Average	Change	% Linearity
0.000	2418	2418	2418		-0.19
0.200	3649	3648	3649	1231	0.06
0.400	4870	4868	4869	1221	0.15
0.600	6079	6083	6081	1212	0.10
0.800	7290	7291	7291	1210	0.01
1.000	8495	8497	8496	1206	-0.15

Calibration Factor (C): 0.0001646 (Inches/Digit)

Regression Zero: 2429

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B":* 5453

or

Position "F":* ______

Date: August 7, 2001

Temperature: 23.4 °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: 4450-3-1

Range: 1"

Serial Number: 18571

Mfg. Number: 01-684

Customer: Loadtest Inc.

Temperature: 24.4 °C

Cust. I.D. #: n/a

Cal. Std. Control #(s): 213, 338, 506, 524, 529

Job Number: 17419

Date of Calibration: July 18, 2001

Technician: CMB

Displacement (inches)	GK-401 Reading Position B Cycle 1	Cycle 2	Average	Change	% Linearity
0.000	1840	1834	1837		-0.27
0.200	3102	3100	3101	1264	0.04
0.400	4362	4355	4359	1258	0.24
0.600	5603	5597	5600	1242	0.19
0.800	6841	6831	6836	1236	0.04
1.000	8065	8059	8062	1226	-0.26

Calibration Factor (C): 0.0001607 (Inches/Digit)

Regression Zero: 1854

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B":* 4979

or

Position "F":* ______

Date: August 7, 2001

Temperature: 23.1 °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: 21305

Customer: Loadtest Inc.

Job Number: 17419

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 23.1 °C

Calibration Date: August 6, 2001

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

Cable Length: 80 ft.

Factory Zero Reading: 6762

Regression Zero: 6776

Technician: CMB

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6834	6835	6835		
1,500	7483	7488	7486	651	-0.37
3,000	8210	8210	8210	725	-0.21
4,500	8937	8941	8939	729	0.10
6,000	9660	9659	9660	721	0.11
100	6835				

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 per cent

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

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

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

Sister Bar Calibration Report

Model Number : 4911-4

Calibration Date: August 6, 2001

Serial Number: 21306

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

Customer: Loadtest Inc.

Cable Length: 80 ft.

Job Number: 17419

Factory Zero Reading: 6722

Cust. I.D. #: n/a

Regression Zero: 6757

Prestress: 35,000 psi

Technician: CMB

Temperature: 22.9 °C

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6821	6809	6815		
1,500	7483	7475	7479	664	-0.31
3,000	8221	8210	8216	737	-0.13
4,500	8958	8951	8955	739	0.13
6,000	9690	9678	9684	730	0.08
100	6810				

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

Gage Factor:

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

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

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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

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

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

Sister Bar Calibration Report

Model Number : 4911-4

Calibration Date: August 6, 2001

Serial Number: 21307

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

Customer: Loadtest Inc.

Cable Length: 80 ft.

Job Number: 17419

Factory Zero Reading: 6773

Cust. I.D. #: n/a

Regression Zero: 6782

Prestress: 35,000 psi

Technician: CMB

Temperature: 23.3 °C

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6836	6835	6836		
1,500	7503	7500	7502	666	-0.19
3,000	8231	8231	8231	730	-0.03
4,500	8961	8962	8962	731	0.16
6,000	9682	9681	9682	720	0.00
100	6836				

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.

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

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: 21308

Customer: Loadtest Inc.

Job Number: 17419

Cust. I.D. #: n/a

Prestress: 35,000 psi

Temperature: 23.3 °C

Calibration Date: August 6, 2001

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

Cable Length: 80 ft.

Factory Zero Reading: 6959

Regression Zero: 6971

Technician: CMB

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7015	7025	7020		
1,500	7687	7691	7689	669	-0.04
3,000	8406	8411	8409	720	-0.03
4,500	9125	9135	9130	722	0.05
6,000	9842	9853	9848	718	-0.01
100	7025				

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

Gage Factor:

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

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

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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

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

APPENDIX C

CONSTRUCTION OF EQUIVALENT TOP-LOAD CURVE

CONSTRUCTION OF THE EQUIVALENT TOP-LOADED LOAD-SETTLEMENT CURVE FROM THE RESULTS OF AN O-CELL™ TEST (June, 1999)

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 F = 0.95 for compression in cohesionless soils and F = 0.80 for tension tests in all soils.

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.

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 is applicable to any approximate determined side shear distribution. Experience has shown the initial solution for the additional elastic compression, as described above, gives an adequate and slightly conservative (high) estimate of the additional compression versus more sophisticated load-transfer analyses as described in the first paragraph of this Part II.

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

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

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

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

Expected Accuracy: We know of only five series of tests that provide the data needed to make a direct comparison between actual, full scale, top-loaded pile movement behavior and the equivalent behavior obtained from an O-cell™ test by the method described herein. These involve three sites in Japan and one in Singapore, in a variety of soils, with three compression tests on bored piles (drilled shafts), one compression test on a driven pile and one tension test on a bored pile. The largest bored pile had a 1.2 m diameter and a 37 m length. The driven pile had a 1-m increment modular construction and a 9 m length. The largest top loading = 28 MN (3,150 tons).

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

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

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

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

B. H. Fellenius has made several finite element method (FEM) studies of an OLT in which he adjusted the parameters to produce good load-deflection matches with the OLT up and down load-deflection curves. He then used the same parameters to predict the TLT deflection curve. We compared the FEM-predicted curve with the equivalent load-deflection predicted by the previously described Part I and II procedures, with the results again comparable to the accuracy noted above. A paper by Fellenius et. al. titled "O-cell Testing and FE Analysis of a 28m Deep Barrette in Manila, Philippines", awaiting publication in the ASCE Journal of Geotechnical and Environmental Engineering, details one of the comparisons.

Limitations: The engineer using these results should judge the conservatism 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.

June, 1999

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

Figure A

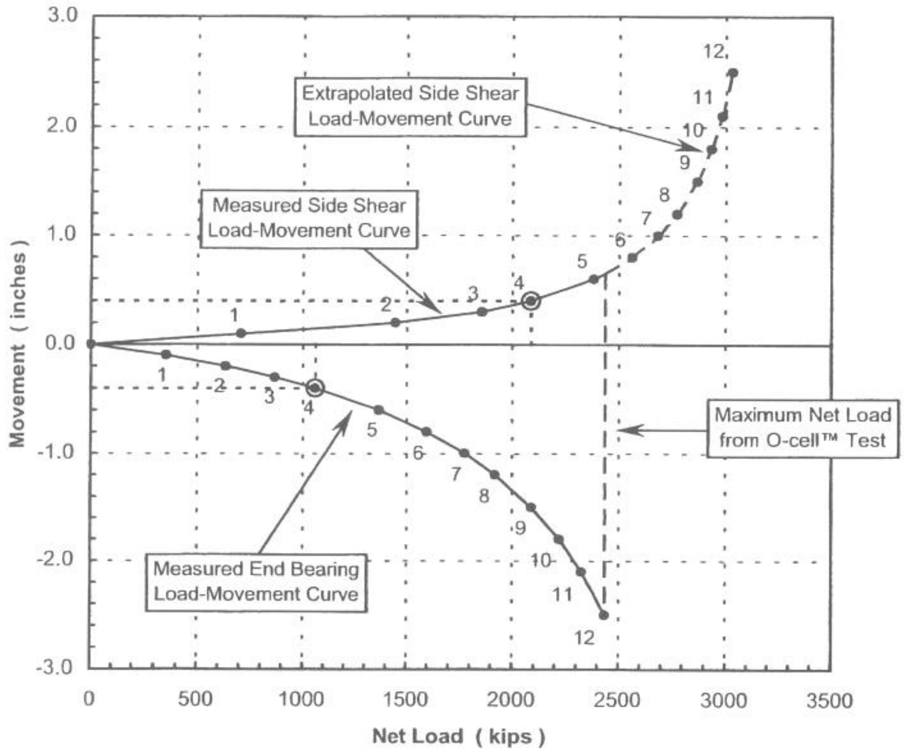
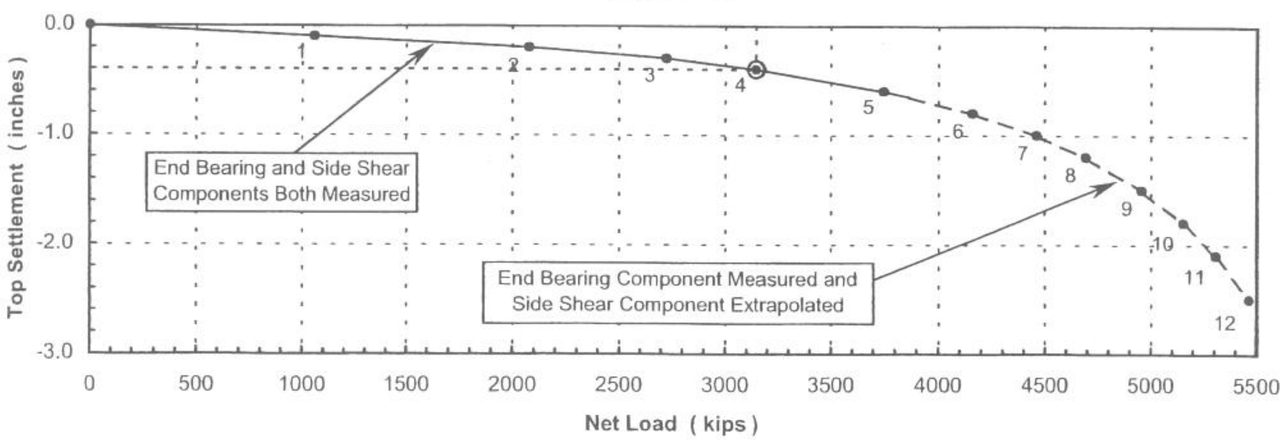
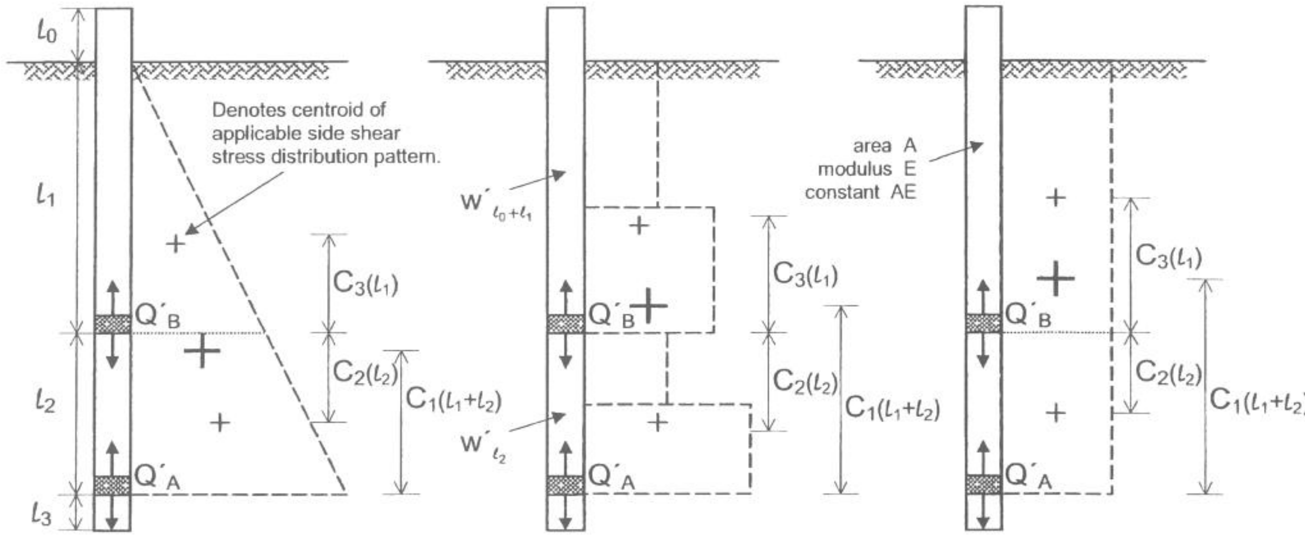


Figure B



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



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

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

3-Stage Multi Level Test (Q'_A and Q'_B): $\delta_{OLT} = \delta_{\uparrow\ell_1} + \delta_{\downarrow\ell_2}$

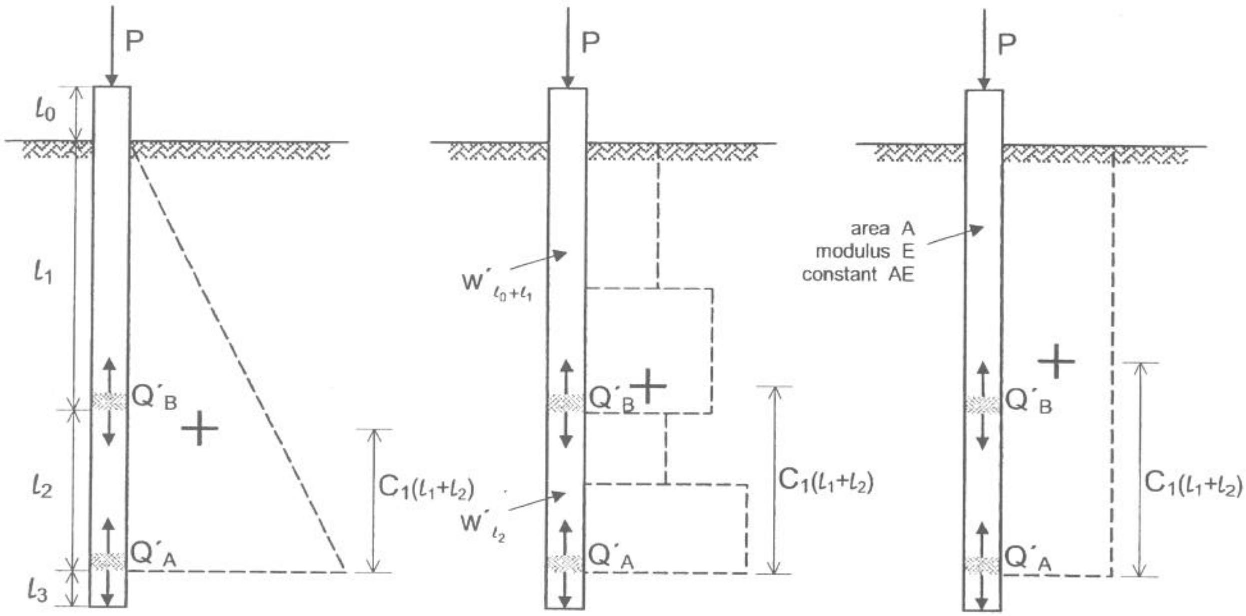
$C_3 = \frac{1}{3}$	$\text{Centroid Factor} = C_3$	$C_3 = \frac{1}{2}$
$\delta_{\uparrow\ell_1} = \frac{1}{3}\frac{Q'_{\uparrow B}\ell_1}{AE}$	$\delta_{\uparrow\ell_1} = C_3\frac{Q'_{\uparrow B}\ell_1}{AE}$	$\delta_{\uparrow\ell_1} = \frac{1}{3}\frac{Q'_{\uparrow B}\ell_1}{AE}$
$C_2 = \frac{1}{3}\left(\frac{3\ell_1+2\ell_2}{2\ell_1+\ell_2}\right)$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

Net Loads:

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

W' = pile weight, bouyant where below water table

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



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

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

Net and Equivalent Loads:

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

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

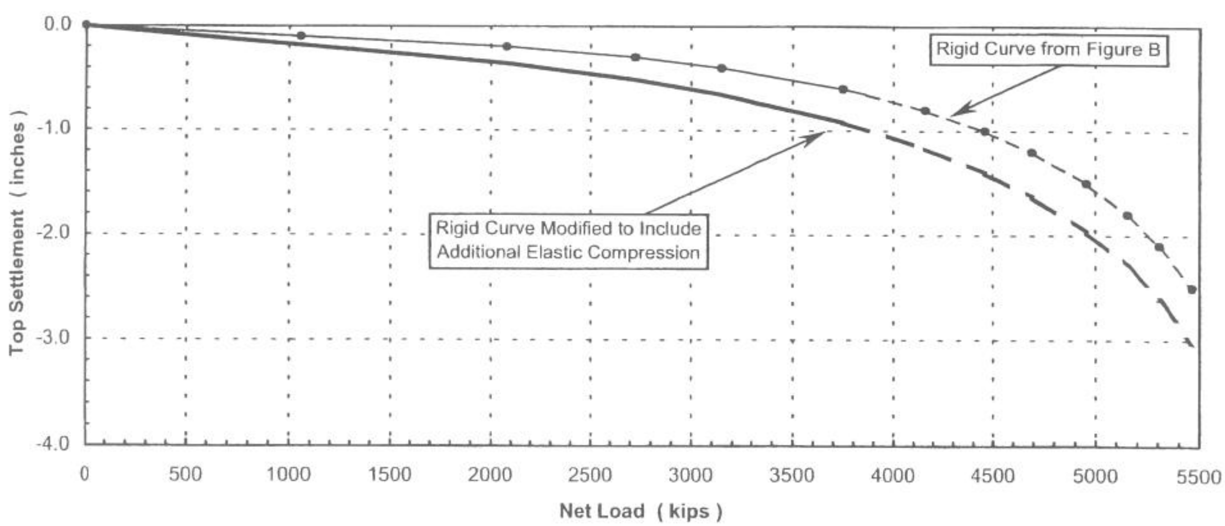
Example Calcuation for the Additional Elastic Compression Correction for Single Level Test (English Units)

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



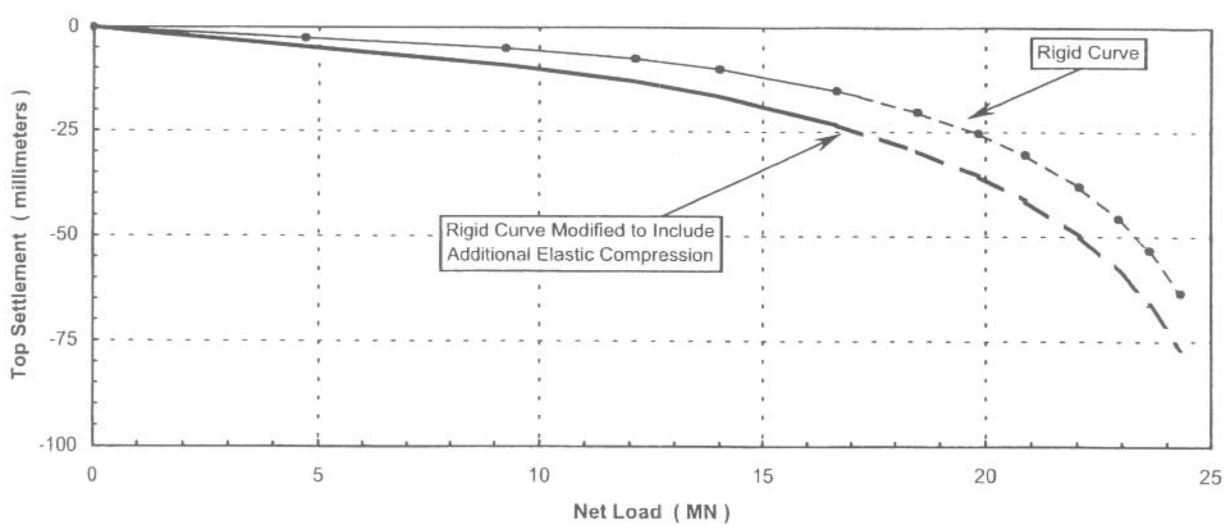
Example Calcuation for the Additional Elastic Compression Correction for Single Level Test (SI Units)

Given:

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

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

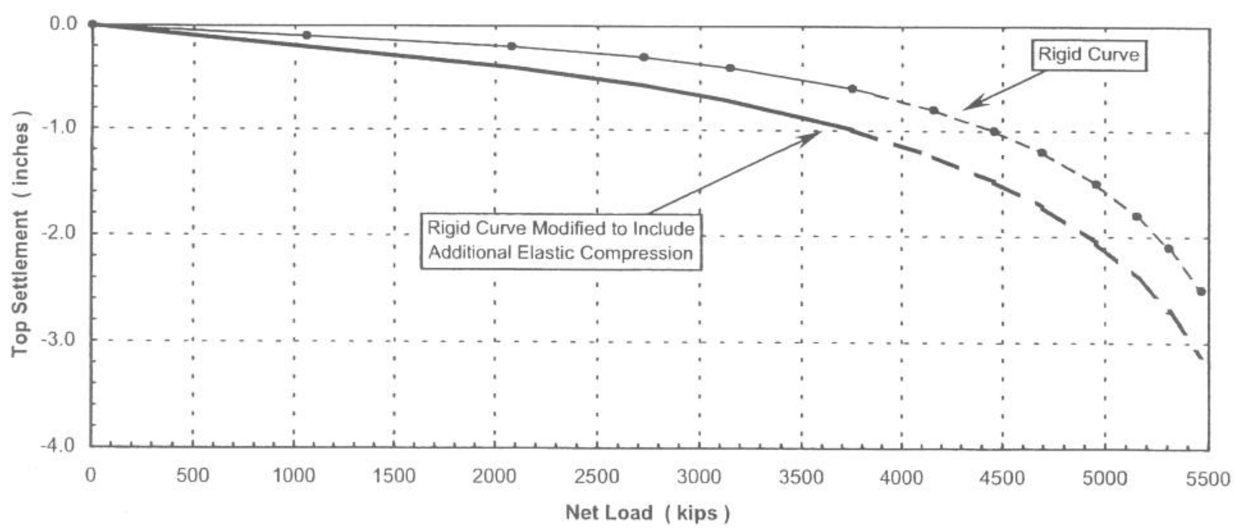
Given:

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

Shear reduction factor = 1.00 (cohesive soil)

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

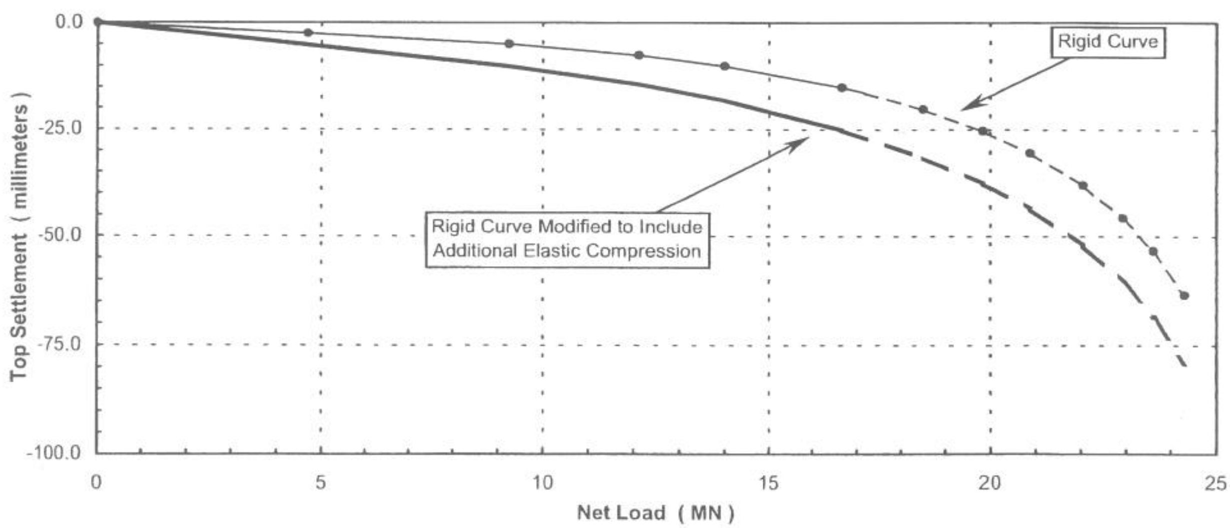
Given:

	C_1 =	0.441	
	C_2 =	0.579	
	C_3 =	0.396	
	AE =	17000	**MN** (assumed constant throughout test)
	ℓ_0 =	1.80	**m**
	ℓ_1 =	9.14	**m** (embedded length of shaft above mid-cell)
	ℓ_2 =	5.55	**m** (embedded length of shaft between O-cells™)
	ℓ_3 =	0.00	**m**

Shear reduction factor = 1.00 (cohesive soil)

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

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

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

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

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

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

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

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

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

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

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

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

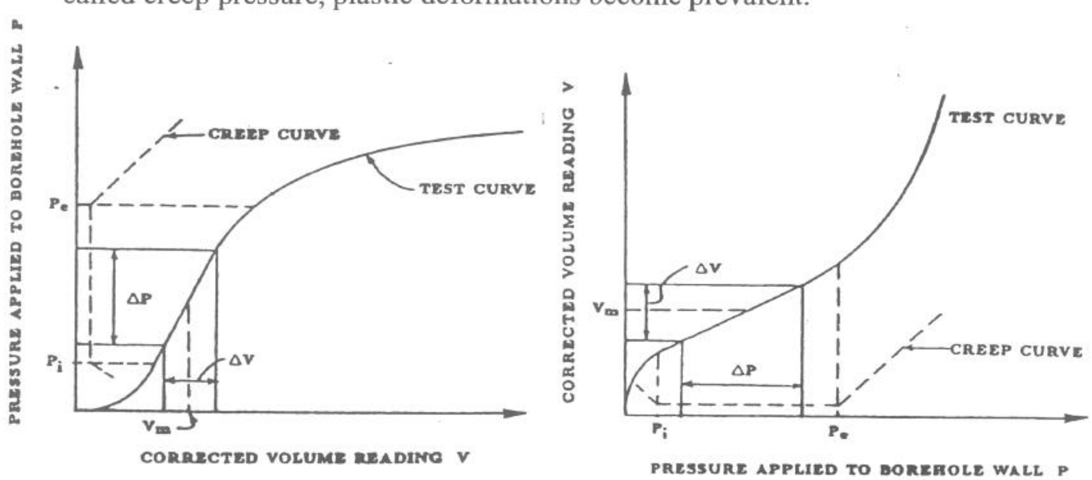


FIG. 8 Pressuremeter Test Curves for Procedure A

References

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

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

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

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

APPENDIX E

NET UNIT SIDE SHEAR VALUES VS. DISPLACEMENT

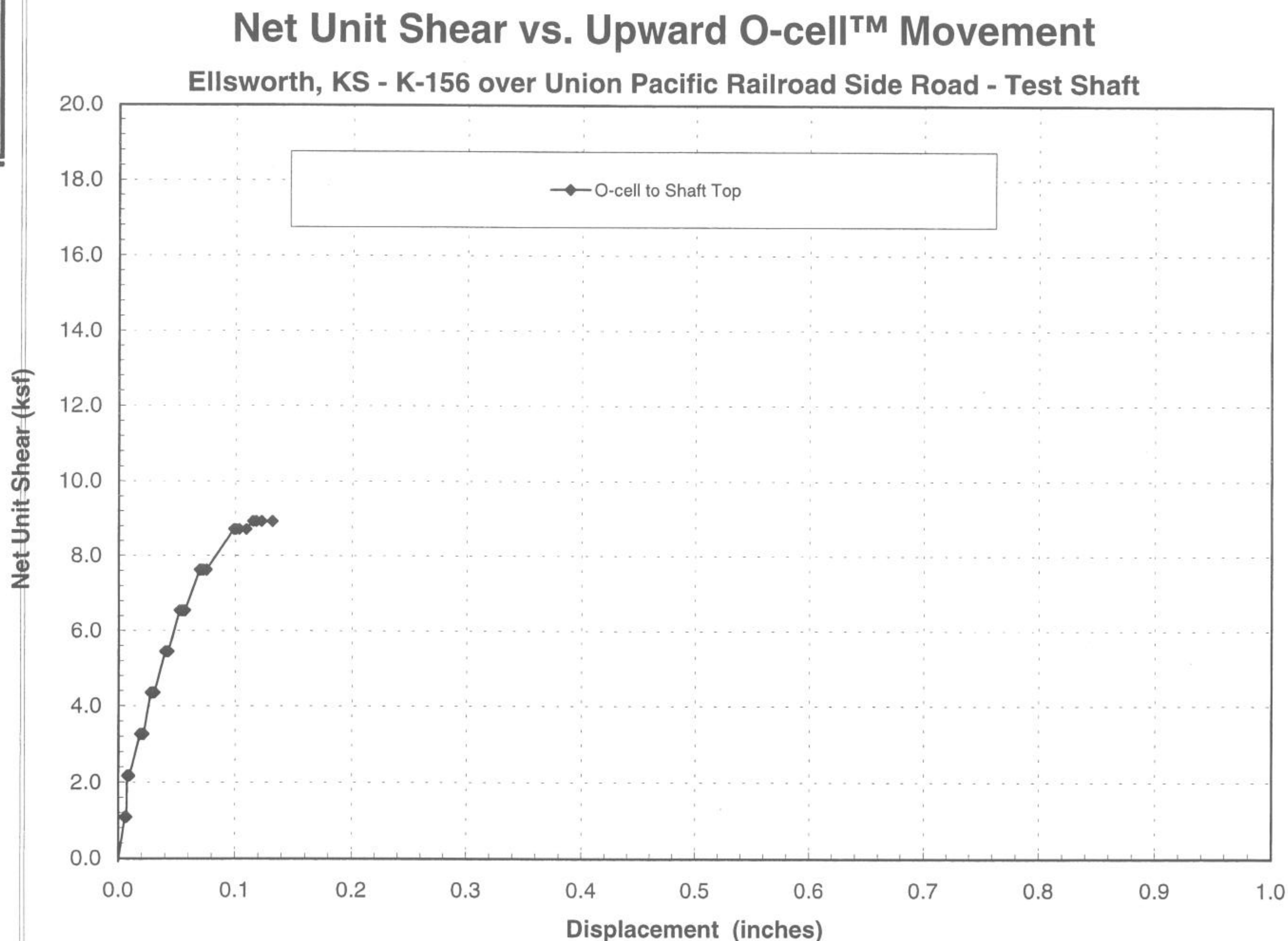

Net Unit Shear vs. Upward O-cell™ Movement
Ellsworth, KS - K-156 over Union Pacific Railroad Side Road - Test Shaft
O-cell to Shaft Top
Net Unit Shear (ksf)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Displacement (inches)

Figure E-1

APPENDIX F

BORING LOG

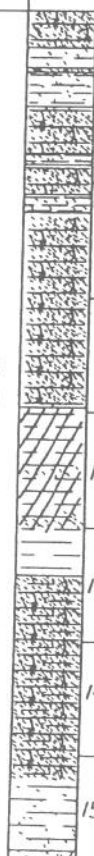
KANSAS DEPARTMENT OF TRANSPORTATION

RTE./CO. K-156 / Ellsworth Co	SOUNDING NO. CD 1	SHEET 1 OF 2
BRIDGE STA. 40+115.350	PROJ. NO. 156-27 K-6802-02	BRIDGE NO. 156-27-18.72(024)
SITE NAME K-156 over UPRR and side road		HOLE STA. 40+168.0, 31.4 Rt
GEOLOGIST J Geist	SCALE 1:100 (10mm=1m)	DATE 3/21/01
DRILLER B Bergman	RIG TYPE Mobile B-61	TOP HOLE ELEV. 466.867
GW ELEV. N/A	TOTAL DEPTH 25.24	M/B ELEV. 463.94

BIT TYPE	GEOLOGIC NAME	STRATIGRAPHIC COLUMN	DEPTH	ELEVATION	CLASSIFICATION OF MATERIALS DESCRIPTION AND REMARKS	UNCONFINED COMPRESSION	STANDARD PENETRATION TEST (SPT) N COUNT	SPT ELEVATION
				467	466.87			
Hawthorne	Alluvium			466	Silty clay, light brown to brown, scattered gravel.	142.8		466.26
				465	Sand, fine to medium, brown, orange-colored at base, some silt binder.	76.8		464.80
			2.90	464	463.94			
NX Carbide	Dakota Formation	1		463	Sandstone, very fine to fine grained with some medium, gray, light brown, yellow-orange, poor to moderately cemented, a few thin, gray, clayey shale sporadically, secondary pyrite and ironstones, organic material along bedding planes, cross-bedded, brittle to firm.		>48	463.60
		2		462				
		3		461				
		4		460				
		5		459				
		6		458				
		7		457				
		8		456				
				455				
				454				

KANSAS DEPARTMENT OF TRANSPORTATION

RTE./CO. K-156 / Ellsworth Co	SOUNDING NO. CD 1	SHEET 2 OF 2
BRIDGE STA. 40+115.350	PROJ. NO. 156-27 K-6802-02	BRIDGE NO. 156-27-18.72(024)
SITE NAME K-156 over UPRR and side road		HOLE STA. 40+168.0, 31.4 Rt



BIT TYPE	GEOLOGIC NAME	STRATIGRAPHIC COLUMN	DEPTH	ELEVATION	CLASSIFICATION OF MATERIALS DESCRIPTION AND REMARKS	UNCONFINED COMPRESSION	SPT N COUNT	SPT ELEVATION
NX Carbide	Dakota Formation	8, 9, 10, 11	19.14	452, 451, 450, 449, 448	Sandstone, light brown, fine grained, very poorly to moderately cemented, thin clayey shale beds. 14.5 15.2 447.73	1348.6 1450.9		449.73 447.73
NX Carbide	Dakota Formation	12	21.36	447, 446	Shale, light gray to gray, firm to soft, weathered and broken, clayey, few thin sandstone lenses. 445.51			
NX Diamond	Dakota Formation	13, 14	24.12	445, 444, 443	Shaley sandstone, hard and competent with a few voids, very dark gray, pyrite nodules. 17.1 442.75	1635.8		443.55
NX Diamond	Dakota Formation	15	25.24	442	Shale, gray to dark gray, numerous sandy seams. 2.4 441.63	225.6		441.91

441

Core	Depth	Elev	Cut	Rec	%	RQD
1	3.29	463.58	0.67	0.50	75	0
2	3.96	462.91	1.53	1.32	86	75
3	5.49	461.38	1.52	1.25	82	45
4	7.01	459.86	1.52	0.00	0	0
5	8.53	458.34	1.53	0.33	22	0
6	10.06	456.81	1.52	0.24	16	0
7	11.58	455.29	1.53	0.00	0	0
8	13.11	453.76	1.52	0.71	47	0
9	14.63	452.24	1.52	0.86	57	80
10	16.15	450.72	1.53	1.09	71	0
11	17.68	449.19	1.52	1.07	70	20
12	19.20	447.67	1.53	1.13	74	0
13	20.73	446.14	1.52	1.52	100	70
14	22.25	444.62	1.52	1.47	97	100
15	23.77	443.10	1.47	1.47	100	95
Total	25.24	441.63	21.95	12.96	59	