

**REPORT ON DRILLED SHAFT
LOAD TESTING (OSTERBERG METHOD)**

**East Test Shaft - US 36 over Republican River
Republic Co., KS (LT-8718-2)**

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

Attention: **Mr. Steve Burnett**

PROJECT NUMBER: LT-8718-2, April 13, 2001

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

April 13, 2001

**Kansas Department of Transportation
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Topeka, Kansas 66612**

Attention: Mr. Steve Burnett

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

Dear Sirs,

This report provides data and evaluation for the Osterberg Cell load test performed for Kansas Department of Transportation on East Test Shaft - US 36 over Republican River (LTI project LT-8718-2). Mr. M. D. Ahrens and Mr. W. G. Ryan of LOADTEST, Inc. carried out the test on April 6, 2001. Representatives of the Kansas Department of Transportation and Midwest Foundations Co. observed the test. Throughout this report, we use SI units as primary and English units as secondary.

Midwest Foundations Co. constructed the dedicated test shaft socketed in rock on March 30, 2001. Assembly and installation of the O-cell™ and instrumentation was carried out under the direction of Mr. W. G. Ryan of LOADTEST, Inc. The 1829 mm (72 in) test shaft was constructed dry to a total depth of 14.94 m (49.0 ft). The shaft was started with a temporary 1829-mm (72-in) I.D. surface casing. An auger and clean-out bucket were used for drilling and cleaning the shaft. After the carrying frame and O-cell™ assembly was inserted in the shaft, concrete was placed by pump through a 127-mm (5-in) O.D. pipe into the base of the shaft until the top of the concrete reached an elevation of +430.49 m (+1412.4 ft). The O-cell™ was located 1.19 m (3.9 ft) above the tip of shaft. No unusual problems occurred during construction of the shaft. Representatives of the Kansas Department of Transportation observed construction of the shaft. Table B contains a summary of dimensions, elevations and shaft properties used in the data evaluations.

The sub-surface stratigraphy at the test shaft location is reported to consist of alluvial silty sand to elevation +431.05 m (+1414.2 ft) underlain by the Graneros Shale Formation to an undetermined depth. Appendix E contains a soil boring log of conditions near the test shaft. More detailed geologic information can be obtained from the Kansas Department of Transportation.

The key elements of the acquired data are as follows:

- Average Net Unit Side Shear Values, Table A.
- Summary of Dimensions, Elevations & Shaft Properties, Table B.
- Schematic Section of Test Shaft, Figure A.
- Osterberg Cell Load-Movement Curves, Figure 1.
- Equivalent Top Load Curve, Figure 2.
- Strain Gage Load Distribution Curves, Figure 3.
- Combined End Bearing and Lower Side Shear Creep Limit, Figure 4.
- Upper Side Shear Creep Limit, Figure 5.
- Field Data & Data Reduction, Appendix A (5 pages).
- O-cell™ and Instrumentation Calibration Sheets, Appendix B.
- Construction of the Equivalent Top-Loaded Load-Settlement Curve, Appendix C.
- O-cell™ Method for Determining Creep Limit Loading, Appendix D.
- Soil Boring Log, Appendix E.
- Reference Beam Monitoring, Appendix F.
- Net Unit Shear and Unit End Bearing Curves, Appendix G.

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

The reference beam consisted of a 6-m (20-ft) steel wide flange section supported on wood dunnage. The supports were located approximately one and a half shaft diameters from the center of the test shaft. The beam was not shaded during the test, however, the sky was completely overcast. A Leica NA 3003 digital survey level monitored the reference beam for movement during testing from a distance of approximately 11.8 m (39 ft) (Appendix F). A maximum upward movement of 0.20 mm (0.008 in) was observed for the reference beam and the top of shaft movements have been corrected accordingly (Table 1).

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

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

American Equipment and Fabricating Corporation carried out a pressure vs. load calibration of the O-cell™ to 13.74 MN (3089 kips) prior to delivery to the test site (See Appendix B). Both a Bourdon pressure gage (0-10,000 psi) and a voltage pressure transducer were used to measure the pressure applied to the O-cell™ at each load interval. We used the Bourdon pressure gage for operating the pump and for data analysis. The transducer readings were used for real time plotting and as a check on the Bourdon gage. There was close agreement between the Bourdon gage and the pressure transducer.

Note: The loads applied by the O-cell™ act in two opposing directions, resisted by the capacity of the shaft above and below. Theoretically, the O-cell™ does not impose an additional upward load until its expansion force exceeds the buoyant weight of the shaft above the O-cell™. Therefore, *net load*, which is defined as gross O-cell™ load minus the buoyant weight of the shaft above, is used to determine side shear resistance above the O-cell™ and to construct the equivalent top load curve. In addition, the buoyant weight of the shaft above the O-cell™ is subtracted a second time, since in a top load test, the applied load is equal to the soil resistance less the buoyant weight of the shaft. For this test we calculated a buoyant weight of shaft of 0.26 MN (58 kips) above the O-cell™.

As with all of our tests, we begin by pressurizing the O-cells™ in order to break the tack welds that hold the cell closed (for handling and construction of the shaft) and to form the fracture plane in the concrete surrounding the base of the O-cells™. After the break occurs, we immediately release the pressure and then begin the test. Zero readings for all instrumentation are taken prior to the preliminary weld-breaking load-unload cycle, which in this case involved a maximum applied pressure of 5.52 MPa (800 psi) to the O-cell™.

The Osterberg cell load test was conducted as follows: We pressurized the 870-mm (34-in) diameter O-cell™, with its base located 1.19 m (3.9 ft) above the base of shaft to assess the combined end bearing and lower side shear below the O-cell™ and the upper side shear above. We pressurized the O-cell™ in 10 loading increments to 16.48 MPa (2390 psi) resulting in a bi-directional gross O-cell™ load of 6.54 MN (1469 kips). The loading was halted after load interval 1L-10 because the O-cell™ was expanding rapidly and a higher load could not be achieved. The O-cell™ was then depressurized in four decrements and the test was concluded.

We applied the load increments in general accordance with the Quick Load Test Method (ASTM D1143), holding each successive load increment constant for eight minutes by manually adjusting the O-cell™ pressure. We used approximately one minute to move between increments. The data logger automatically recorded the

instrument readings every 30 seconds, but herein we report only the 1, 2, 4 and 8 minute readings during each increment of maintained load.

DISCUSSION OF RESULTS

Combined End Bearing and Lower Side Shear: The maximum downward applied load was 6.54 MN (1469 kips) which occurred at load interval 1L-10 (Table 3, Figure 1). At this loading, the downward movement of the O-cell™ base was 15.71 mm (0.619 in). The side shear capacity of the 1.19 m (3.9 ft) shaft section below the O-cell™ is calculated to be 0.99 MN (223 kips) assuming an average socket unit side shear value of 144 kPa (3.01 ksf) (Appendix G) and a nominal shaft diameter of 1829 mm (72 in). The maximum applied load to end bearing is then 5.55 MN (1247 kips) and the unit end bearing at the base of the shaft is calculated to be 2111 kPa (44.1 ksf) at the above noted displacement. A unit end bearing curve is presented in Appendix G.

Upper Side Shear: The maximum upward applied *net load* was 6.28 MN (1412 kips) which occurred at load interval 1L-10 (Table 3, Figure 1). At this loading, the upward movement of the O-cell™ top was 52.98 mm (2.086 in). The following section provides additional unit side shear estimates based on strain gage data.

Strain Gage Results: The strain gage data appear in Table 5. On the day of the test, the concrete unconfined compressive strength was reported to be 41.4 MPa (6011 psi). We used the ACI formula ($E_c = 57000\sqrt{f'_c}$) to calculate an elastic modulus for the concrete. This, combined with the area of reinforcing steel and nominal shaft diameter, provided an average pile stiffness (AE) of 80,500 MN (18,100,000 kips) above the O-cell™. Net unit side shear curves based on the strain gage data and estimated shaft stiffness are presented in Appendix G. Estimated unit side shear values for the shaft based on the strain gage data and estimated shaft stiffness for 1L-10 follow in Table A:

TABLE A: Average Net Unit Side Shear Values for 1L-10

Load Transfer Zone	Net Unit Side Shear *
Average Socket – Top of Concrete to O-cell™	156 kPa (3.26 ksf)
Top of Concrete to Strain Gage Level 2	189 kPa (3.95 ksf)
Strain Gage Level 2 to Strain Gage Level 1	114 kPa (2.38 ksf)
Strain Gage Level 1 to O-cell™	188 kPa (3.93 ksf)

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

Creep Limit: See Appendix D for our O-cell™ method for determining creep limit loading. The combined end bearing and lower side shear creep data (Table 4) indicate that a creep limit of 1.6 MN (360 kips) was reached at a movement of 0.8 mm (0.03 in) (Figure 4). The upper side shear creep data (Table 4) indicate that a creep limit of 4.7 MN (1057 kips) was reached at a movement of 5.0 mm (0.20 in)



(Figure 5). A shaft top loaded will not begin significant creep until both components begin creep movement. This will occur at the maximum of the movements required to reach the creep limit for each component. We believe that significant creep for this shaft will not begin until a top loading exceeds 8.5 MN (1914 kips).

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

The test shaft was successfully loaded to a combined side shear and end-bearing load of 12.8 MN (2881 kips). For a top loading of 9.0 MN (2029 kips), the adjusted test data indicate this shaft would settle approximately 6.4 mm (0.25 in) of which 0.6 mm (0.02 in) is estimated elastic compression. For a top loading of 11.3 MN (2533 kips) the adjusted test data indicate this shaft would settle approximately 12.7 mm (0.50 in) of which 0.8 mm (0.03 in) is estimated elastic compression.

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

Shaft Compression Telltales: The measured maximum shaft compression, averaged from two telltales, is 0.18 mm (0.007 in) at 1L-10 (Table 1). Using a shaft stiffness of 80,500 MN (18,100,000 kips) and the load distribution in Figure 3 at 1L-10, we calculated an elastic compression of 0.24 mm (0.009 in) over the length of the compression telltales. We believe this fair agreement provides evidence that our values of the estimated shaft stiffness are reasonable and that the O-cells™ loaded the shaft in accord with its calibrations.

Differential O-cell™ Opening: The three LWWDTs measuring O-cell™ expansion allow us to evaluate the differential opening of the O-cell™ (Table 2). We calculate a maximum differential expansion of 1.73 mm (0.068 in) (0.10°) across the nominal 1829 mm (72 in) diameter of the bottom of the shaft at the 1L-10 maximum loading. This suggests uniform concrete above and below the O-cell™.

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

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

Prepared for LOADTEST, Inc. by



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Geotechnical Engineer

Reviewed by



for William G. Ryan
Midwest Regional Manager



John H. Schmertmann, Ph.D., P.E.
For John H. Schmertmann, Inc.



TABLE B:
SUMMARY OF DIMENSIONS, ELEVATIONS & SHAFT PROPERTIES

Shaft:

Nominal shaft diameter (EL +430.49 m to +423.48 m)	=	1829 mm	72 in
O-cell™: 0034-5	=	870 mm	34 in
Bouyant weight of pile above base of O-cell™	=	0.26 MN	58 kips
Estimated shaft stiffness, AE (EL +430.49 m to +423.48 m)	=	80,500 MN	18,100,000 kips

Elevation of ground surface	=	+437.22 m	+1434.4 ft
Elevation of water table	=	+434.68 m	+1426.1 ft
Elevation of top of shaft concrete	=	+430.49 m	+1412.4 ft
Elevation of base of O-cell™ (The break between upward and downward movement.)	=	+423.48 m	+1389.4 ft
Elevation of shaft tip	=	+422.28 m	+1385.4 ft

Casings:

Elevation of top of temporary casing (1829 mm O.D.)	=	+437.50 m	+1435.4 ft
Elevation of bottom of temporary casing (1829 mm O.D.)	=	+430.64 m	+1412.9 ft

Compression Sections:

Elevation of top of telltale used for upper shaft compression	=	+430.49 m	+1412.4 ft
Elevation of bottom of telltale used for upper shaft compression	=	+430.49 m	+1412.4 ft

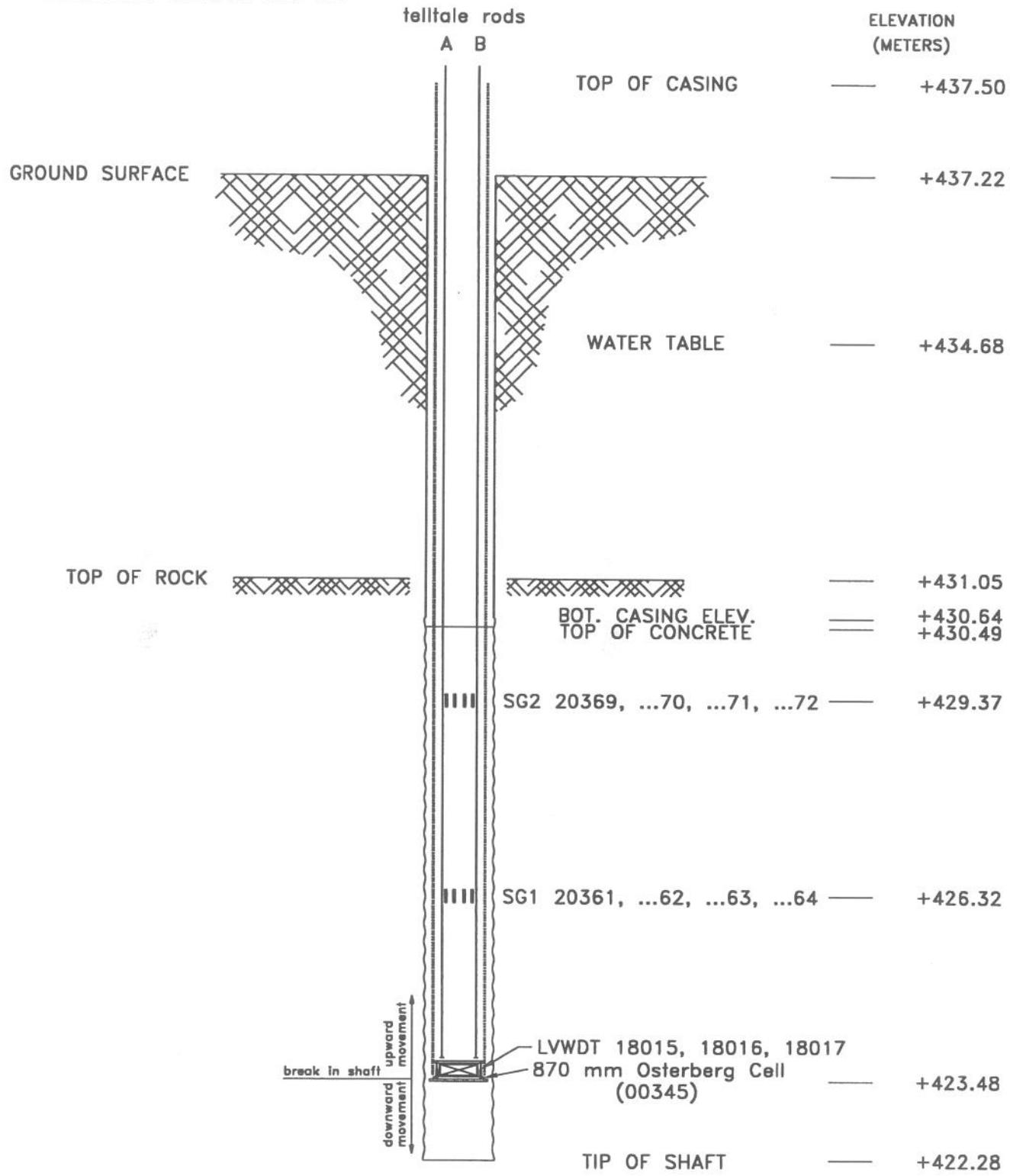
Strain Gages:

Elevation of strain gage Level 2	=	+429.37 m	+1408.7 ft
Elevation of strain gage Level 1	=	+426.32 m	+1398.7 ft

Miscellaneous:

Top plate diameter (38 mm thickness)	=	1676 mm	66 in
Bottom plate diameter (51 mm in thickness)	=	1676 mm	66 in
Carrying frame size (2 No.)	=		C4 x 7.25
Spiral size (1524 mm spacing)	=	M 16	# 5
Rebar cage diameter	=	1676 mm	66 in
Unconfined compressive concrete strength	=	41.4 MPa	6011 psi
O-cell™ LVWDTs @ 0°, 180° and 90° with radius	=	500 mm	20 in

NOTE:
- NOMINAL SHAFT DIAMETER 1829 mm

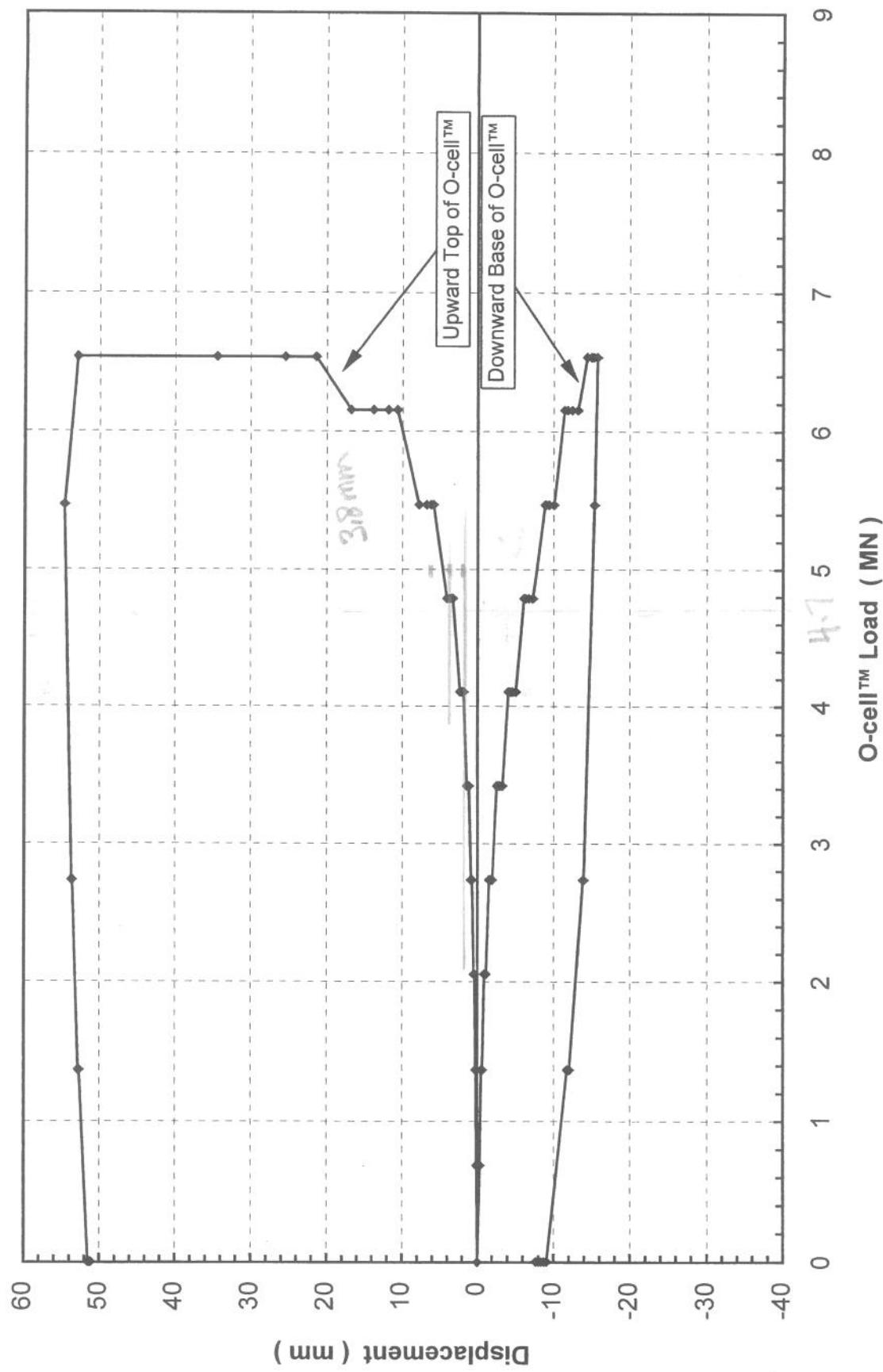


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SCHEMATIC SECTION OF
EAST TEST SHAFT

LT-8718-2 US36
Over Republican River
Scandia, Kansas
FIGURE A

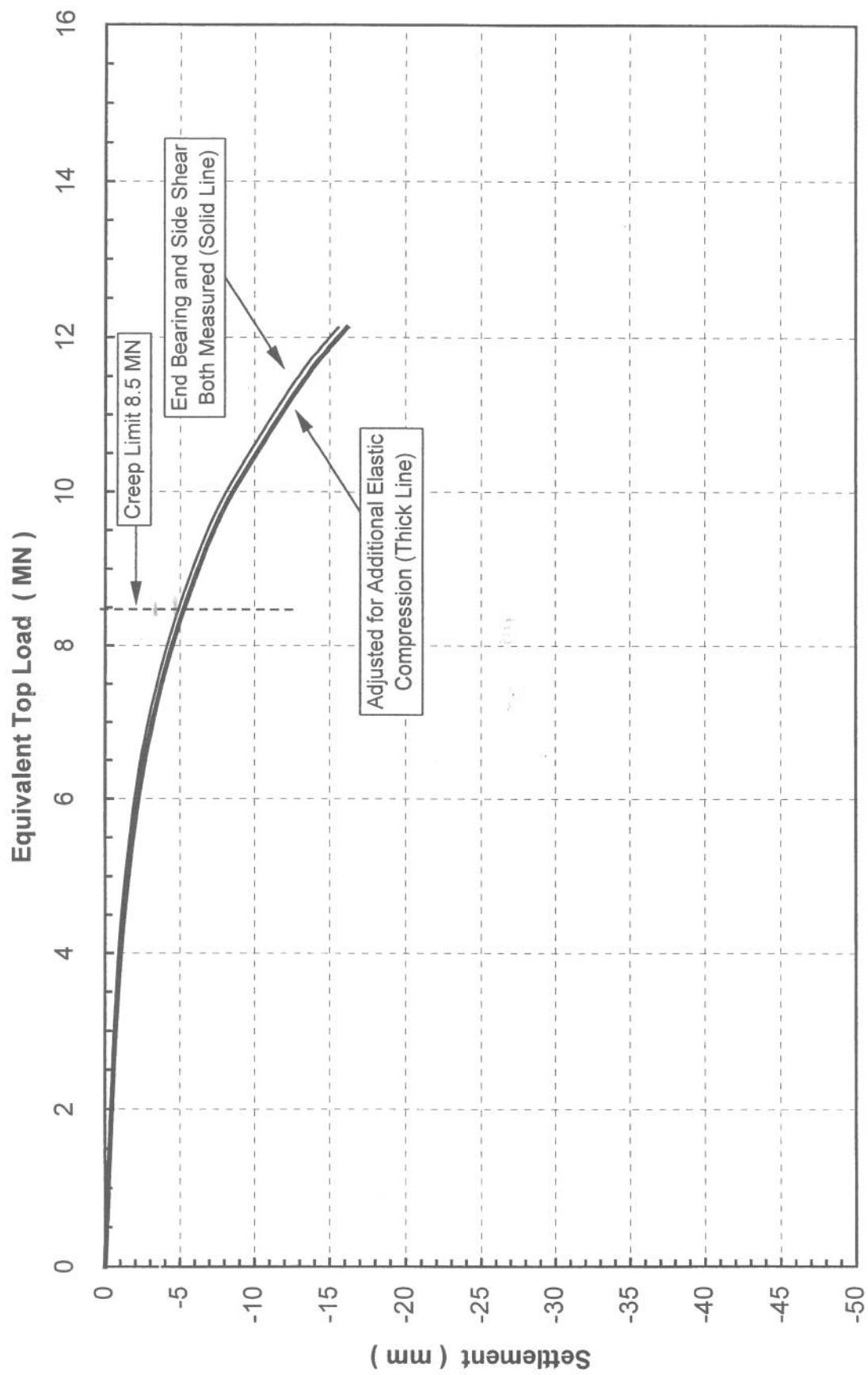
Osterberg Cell Load-Movement Curves East Test Shaft - US 36 over Republican River - Republic Co., KS



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Equivalent Top Load-Movement Curves

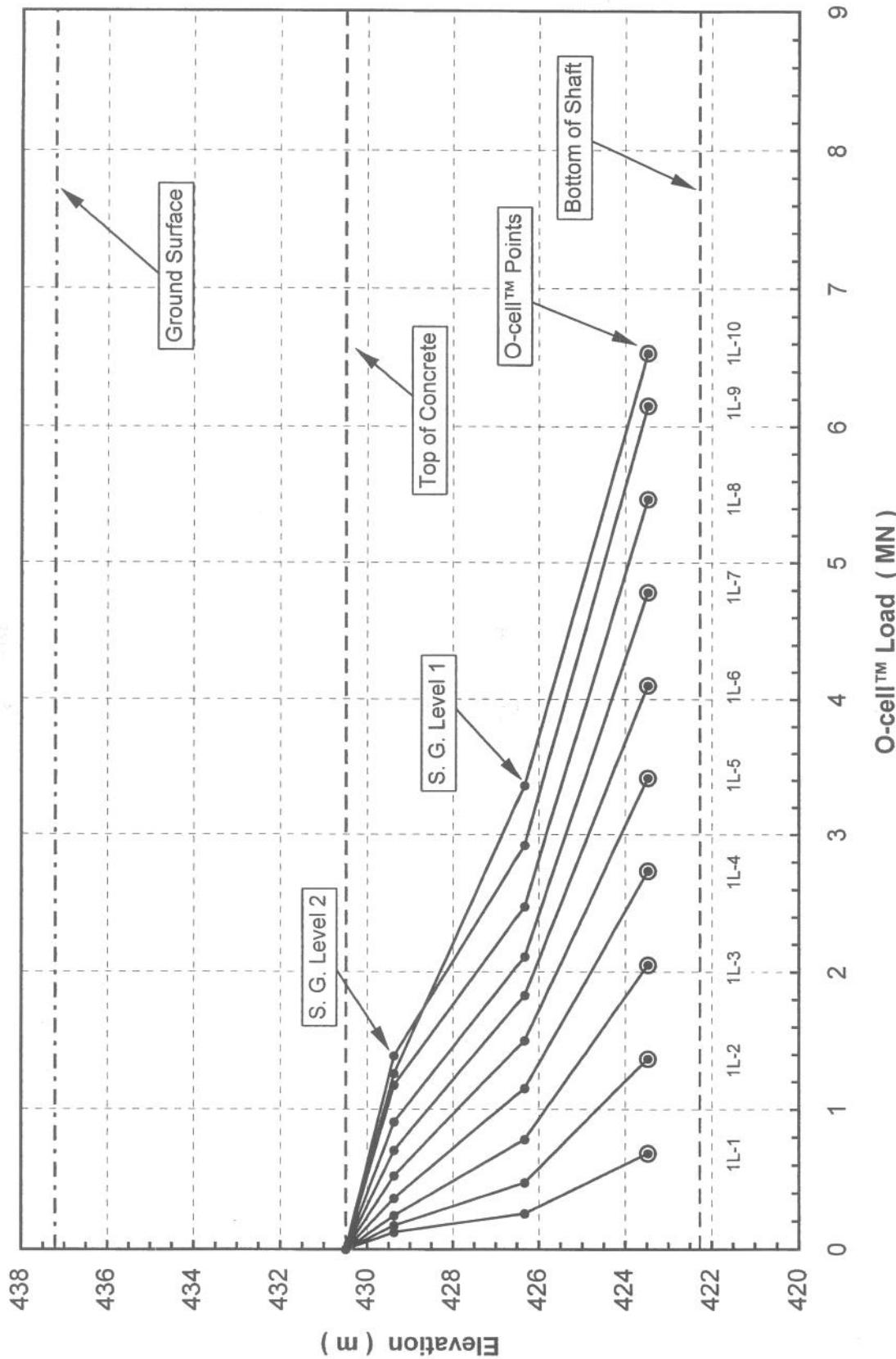
East Test Shaft - US 36 over Republican River - Republic Co., KS



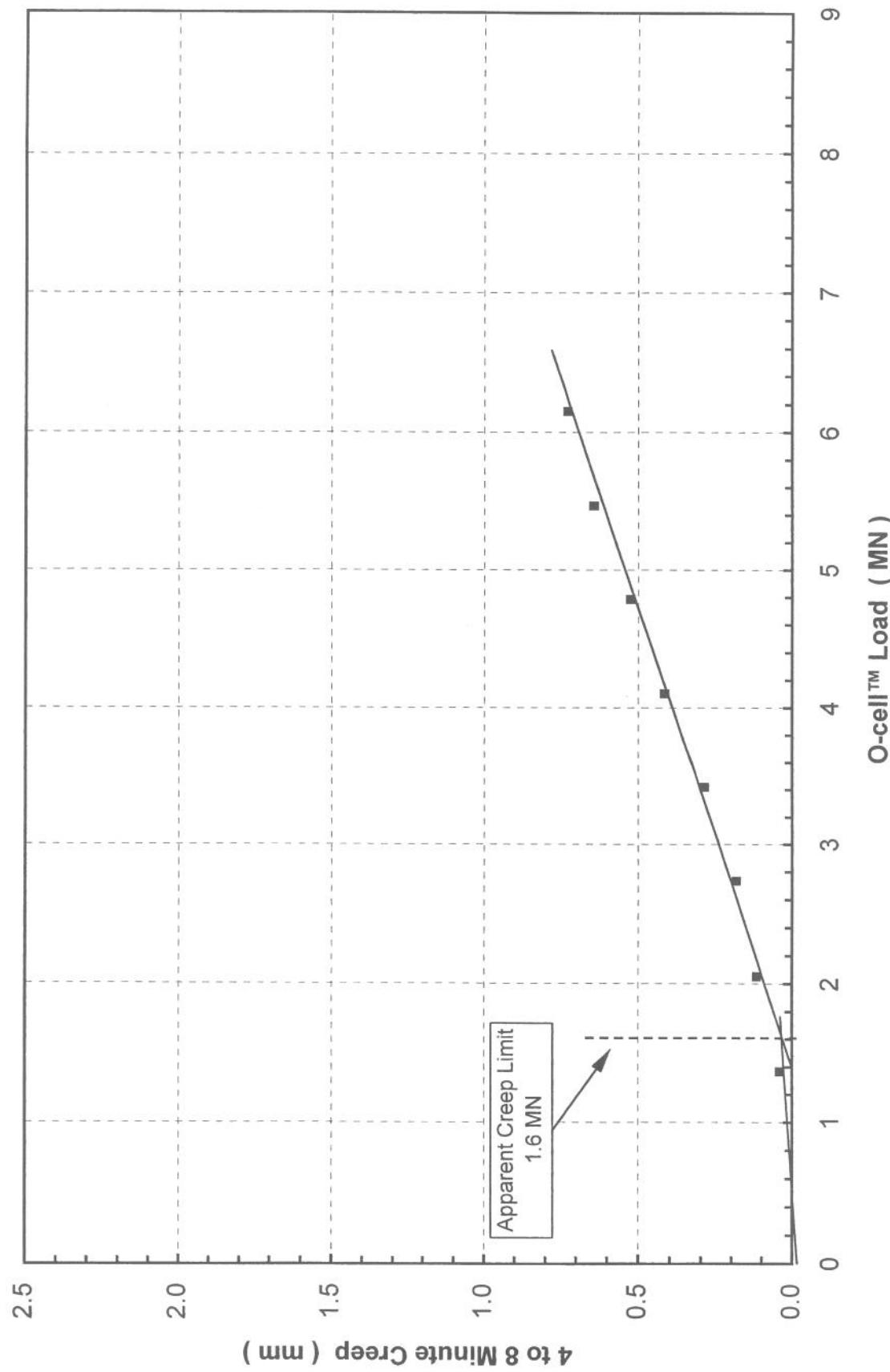
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Strain Gage Load Distribution Curves

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

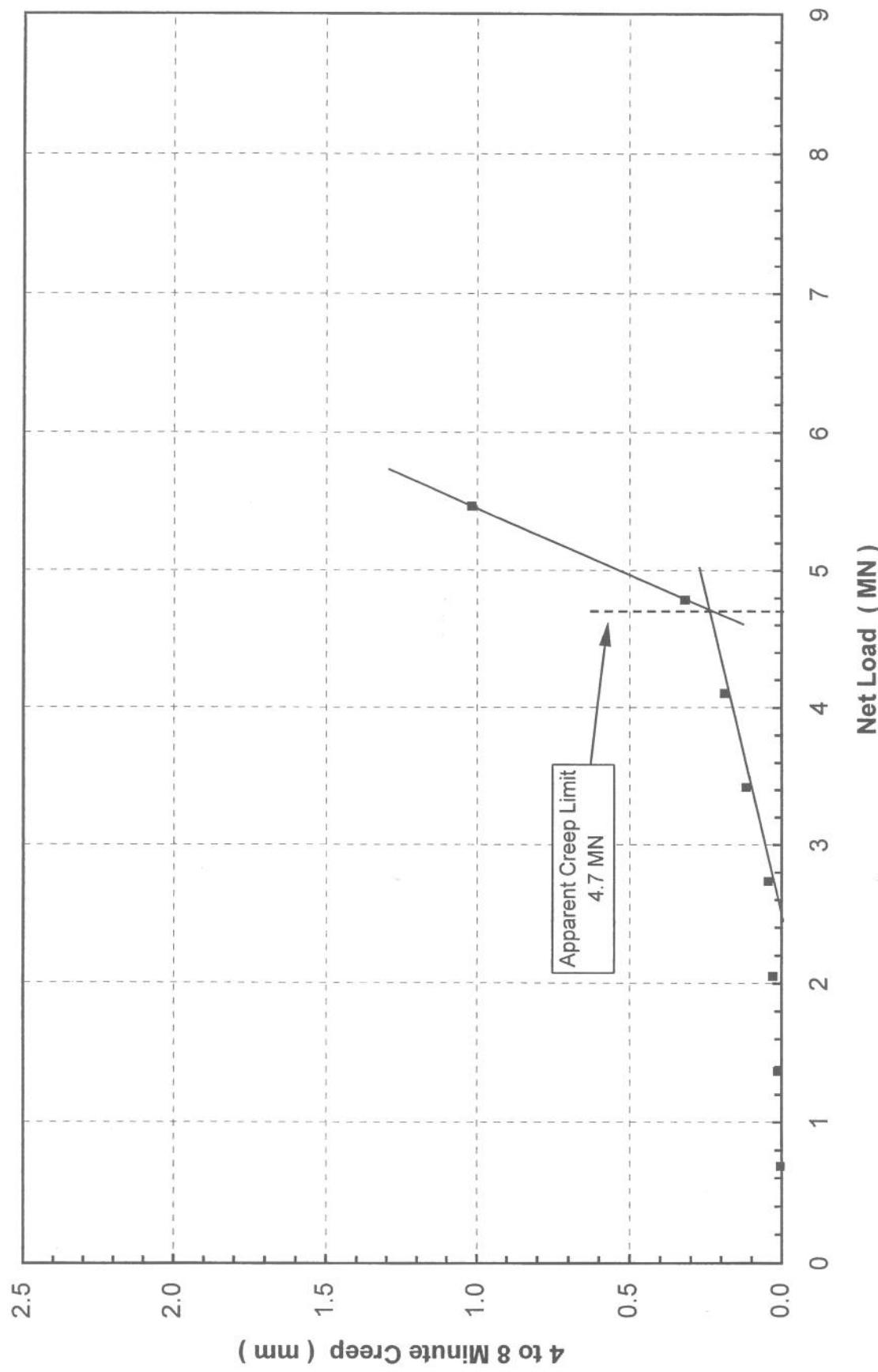


Combined End Bearing and Lower Side Shear Creep Limit
East Test Shaft - US 36 over Republican River - Republic Co., KS



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Upper Side Shear Creep Limit
East Test Shaft - US 36 over Republican River - Republic Co., KS



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APPENDIX A

FIELD DATA & DATA REDUCTION



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

Load Test Increment	Hold Time (minutes)	Time (h:m:s)	O-cell™		Ref. Beam * (mm)	Top of Shaft			Telltale		
			Pressure (MPa)	Load (MN)		TOS A (mm)	TOS B (mm)	Average (mm)	Comp A (mm)	Comp B (mm)	Average (mm)
1L-0	-	10:32:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1L-1	1	10:44:30	1.72	0.69	-0.02	0.11	0.12	0.10	0.01	0.00	0.01
1L-1	2	10:45:30	1.72	0.69	-0.02	0.11	0.12	0.10	0.01	0.00	0.01
1L-1	4	10:47:30	1.72	0.69	-0.02	0.12	0.14	0.11	0.01	0.00	0.01
1L-1	8	10:51:30	1.72	0.69	-0.02	0.12	0.14	0.11	0.01	0.00	0.01
1L-2	1	10:53:00	3.45	1.37	-0.02	0.21	0.22	0.20	0.01	0.00	0.01
1L-2	2	10:54:00	3.45	1.37	-0.02	0.22	0.24	0.21	0.01	0.00	0.01
1L-2	4	10:56:00	3.45	1.37	-0.02	0.24	0.26	0.23	0.02	0.00	0.01
1L-2	8	11:00:00	3.45	1.37	-0.03	0.25	0.29	0.25	0.02	0.00	0.01
1L-3	1	11:01:30	5.17	2.05	-0.01	0.38	0.40	0.39	0.03	0.01	0.02
1L-3	2	11:02:30	5.17	2.05	-0.01	0.41	0.43	0.41	0.03	0.01	0.02
1L-3	4	11:04:30	5.17	2.05	0.01	0.43	0.46	0.46	0.03	0.01	0.02
1L-3	8	11:08:30	5.17	2.05	0.01	0.46	0.49	0.49	0.03	0.01	0.02
1L-4	1	11:10:00	6.89	2.74	0.02	0.66	0.68	0.69	0.04	0.03	0.04
1L-4	2	11:11:00	6.89	2.74	0.03	0.70	0.73	0.74	0.04	0.03	0.04
1L-4	4	11:13:00	6.89	2.74	0.02	0.75	0.78	0.78	0.05	0.03	0.04
1L-4	8	11:17:00	6.89	2.74	0.02	0.79	0.82	0.83	0.05	0.03	0.04
1L-5	1	11:18:30	8.62	3.42	0.03	1.04	1.06	1.08	0.06	0.05	0.05
1L-5	2	11:19:30	8.62	3.42	0.03	1.12	1.14	1.16	0.06	0.05	0.06
1L-5	4	11:21:30	8.62	3.42	0.03	1.19	1.22	1.23	0.06	0.05	0.06
1L-5	8	11:25:30	8.62	3.42	0.05	1.28	1.32	1.35	0.06	0.05	0.06
1L-6	1	11:27:00	10.34	4.10	0.04	1.70	1.73	1.76	0.07	0.07	0.07
1L-6	2	11:28:00	10.34	4.10	0.03	1.84	1.87	1.88	0.07	0.07	0.07
1L-6	4	11:30:00	10.34	4.10	0.05	1.99	2.02	2.06	0.07	0.07	0.07
1L-6	8	11:34:00	10.34	4.10	0.06	2.17	2.20	2.24	0.08	0.08	0.08
1L-7	1	11:36:00	12.07	4.79	0.08	3.09	3.11	3.18	0.09	0.09	0.09
1L-7	2	11:37:00	12.07	4.79	0.09	3.28	3.30	3.38	0.09	0.09	0.09
1L-7	4	11:39:00	12.07	4.79	0.09	3.54	3.57	3.65	0.09	0.09	0.09
1L-7	8	11:43:00	12.07	4.79	0.10	3.86	3.88	3.97	0.09	0.09	0.09
1L-8	1	11:45:00	13.79	5.47	0.11	5.62	5.63	5.74	0.10	0.11	0.10
1L-8	2	11:46:00	13.79	5.47	0.13	5.96	5.96	6.09	0.10	0.11	0.10
1L-8	4	11:48:00	13.79	5.47	0.16	6.48	6.48	6.64	0.10	0.11	0.10
1L-8	8	11:52:00	13.79	5.47	0.14	7.49	7.52	7.65	0.11	0.11	0.11
1L-9	1	11:53:30	15.51	6.15	0.17	10.32	10.32	10.49	0.11	0.14	0.13
1L-9	2	11:54:30	15.51	6.15	0.17	11.55	11.54	11.72	0.11	0.14	0.13
1L-9	4	11:56:30	15.51	6.15	0.17	13.49	13.46	13.64	0.11	0.15	0.13
1L-9	8	12:00:30	15.51	6.15	0.20	16.47	16.44	16.65	0.11	0.18	0.14
1L-10	1	12:02:00	16.48	6.54	0.21	21.05	20.99	21.22	0.11	0.20	0.16
1L-10	2	12:03:00	16.48	6.54	0.20	25.14	25.04	25.29	0.11	0.22	0.17
1L-10	4	12:05:00	16.48	6.54	0.21	34.12	33.99	34.26	0.10	0.24	0.17
1L-10	8	12:09:00	16.48	6.54	0.20	52.65	52.54	52.80	0.09	0.26	0.18
1U-1	1	12:10:30	13.79	5.47	0.19	54.39	54.26	54.52	0.07	0.26	0.17
1U-1	2	12:11:30	13.79	5.47	0.18	54.42	54.30	54.54	0.07	0.26	0.17
1U-1	4	12:13:30	13.79	5.47	0.14	54.48	54.37	54.57	0.07	0.26	0.17
1U-2	1	12:15:30	6.89	2.74	0.03	53.67	53.57	53.65	-0.01	0.18	0.09
1U-2	2	12:16:30	6.89	2.74	0.02	53.63	53.52	53.60	-0.01	0.18	0.09
1U-2	4	12:18:30	6.89	2.74	0.00	53.60	53.49	53.54	-0.01	0.18	0.09
1U-3	1	12:20:00	3.45	1.37	-0.04	52.88	52.78	52.79	-0.05	0.14	0.04
1U-3	2	12:21:00	3.45	1.37	-0.05	52.82	52.72	52.72	-0.05	0.13	0.04
1U-3	4	12:23:00	3.45	1.37	-0.08	52.78	52.69	52.66	-0.05	0.13	0.04
1U-4	1	12:24:30	0.00	0.00	-0.13	51.74	51.65	51.57	-0.07	0.08	0.00
1U-4	2	12:25:30	0.00	0.00	-0.16	51.64	51.55	51.44	-0.07	0.08	0.00
1U-4	4	12:27:30	0.00	0.00	-0.17	51.56	51.46	51.34	-0.07	0.07	0.00
1U-4	8	12:31:30	0.00	0.00	-0.18	51.48	51.39	51.26	-0.07	0.07	0.00
1U-4	16	12:39:30	0.00	0.00	-0.21	51.40	51.32	51.15	-0.07	0.07	0.00

* Positive values indicate upward reference beam movement.



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

Load Test Increment	Hold Time (minutes)	Time (h:m:s)	O-cell™		O-cell™ Expansion			Average (mm)
			Pressure (MPa)	Load (MN)	LVWDT 18015 (mm)	LVWDT 18016 (mm)	LVWDT 18017* (mm)	
1 L - 0	-	10:32:00	0.00	0.00	0.00	0.00	0.00	0.00
1 L - 1	1	10:44:30	1.72	0.69	0.46	0.44	0.47	0.45
1 L - 1	2	10:45:30	1.72	0.69	0.45	0.45	0.46	0.45
1 L - 1	4	10:47:30	1.72	0.69	0.47	0.45	0.48	0.46
1 L - 1	8	10:51:30	1.72	0.69	0.46	0.44	0.50	0.45
1 L - 2	1	10:53:00	3.45	1.37	0.75	0.66	0.84	0.70
1 L - 2	2	10:54:00	3.45	1.37	0.76	0.68	0.83	0.72
1 L - 2	4	10:56:00	3.45	1.37	0.92	0.74	0.92	0.83
1 L - 2	8	11:00:00	3.45	1.37	0.98	0.79	0.98	0.88
1 L - 3	1	11:01:30	5.17	2.05	1.43	1.21	1.46	1.32
1 L - 3	2	11:02:30	5.17	2.05	1.53	1.32	1.56	1.42
1 L - 3	4	11:04:30	5.17	2.05	1.61	1.39	1.64	1.50
1 L - 3	8	11:08:30	5.17	2.05	1.77	1.53	1.82	1.65
1 L - 4	1	11:10:00	6.89	2.74	2.33	2.21	2.57	2.27
1 L - 4	2	11:11:00	6.89	2.74	2.52	2.40	2.76	2.46
1 L - 4	4	11:13:00	6.89	2.74	2.73	2.62	3.01	2.67
1 L - 4	8	11:17:00	6.89	2.74	2.95	2.85	3.23	2.90
1 L - 5	1	11:18:30	8.62	3.42	3.85	3.70	4.17	3.77
1 L - 5	2	11:19:30	8.62	3.42	4.11	3.98	4.45	4.05
1 L - 5	4	11:21:30	8.62	3.42	4.41	4.27	4.72	4.34
1 L - 5	8	11:25:30	8.62	3.42	4.82	4.67	5.15	4.75
1 L - 6	1	11:27:00	10.34	4.10	6.03	5.85	6.38	5.94
1 L - 6	2	11:28:00	10.34	4.10	6.39	6.26	6.75	6.32
1 L - 6	4	11:30:00	10.34	4.10	6.90	6.65	7.20	6.77
1 L - 6	8	11:34:00	10.34	4.10	7.52	7.23	7.77	7.38
1 L - 7	1	11:36:00	12.07	4.79	9.53	9.25	9.91	9.39
1 L - 7	2	11:37:00	12.07	4.79	10.01	9.69	10.33	9.85
1 L - 7	4	11:39:00	12.07	4.79	10.70	10.28	10.98	10.49
1 L - 7	8	11:43:00	12.07	4.79	11.57	11.10	11.75	11.33
1 L - 8	1	11:45:00	13.79	5.47	14.96	14.46	15.11	14.71
1 L - 8	2	11:46:00	13.79	5.47	15.58	14.95	15.72	15.26
1 L - 8	4	11:48:00	13.79	5.47	16.49	15.87	16.71	16.18
1 L - 8	8	11:52:00	13.79	5.47	18.21	17.47	18.26	17.84
1 L - 9	1	11:53:30	15.51	6.15	22.54	21.58	22.60	22.06
1 L - 9	2	11:54:30	15.51	6.15	24.26	23.19	24.23	23.73
1 L - 9	4	11:56:30	15.51	6.15	26.76	25.71	26.77	26.23
1 L - 9	8	12:00:30	15.51	6.15	30.55	29.42	30.45	29.99
1 L - 10	1	12:02:00	16.48	6.54	36.52	35.07	36.44	35.80
1 L - 10	2	12:03:00	16.48	6.54	41.23	39.66	41.10	40.44
1 L - 10	4	12:05:00	16.48	6.54	50.74	48.64	50.35	49.69
1 L - 10	8	12:09:00	16.48	6.54	70.04	67.34	69.52	68.69
1 U - 1	1	12:10:30	13.79	5.47	71.34	68.81	70.68	70.08
1 U - 1	2	12:11:30	13.79	5.47	71.31	68.83	70.70	70.07
1 U - 1	4	12:13:30	13.79	5.47	71.35	68.83	70.72	70.09
1 U - 2	1	12:15:30	6.89	2.74	68.48	66.93	67.97	67.69
1 U - 2	2	12:16:30	6.89	2.74	68.32	66.87	67.83	67.59
1 U - 2	4	12:18:30	6.89	2.74	68.23	66.74	67.73	67.48
1 U - 3	1	12:20:00	3.45	1.37	65.53	64.31	65.11	64.92
1 U - 3	2	12:21:00	3.45	1.37	65.29	64.08	64.83	64.69
1 U - 3	4	12:23:00	3.45	1.37	65.11	63.88	64.66	64.49
1 U - 4	1	12:24:30	0.00	0.00	60.98	60.36	60.76	60.67
1 U - 4	2	12:25:30	0.00	0.00	60.52	59.88	60.33	60.20
1 U - 4	4	12:27:30	0.00	0.00	60.06	59.34	59.84	59.70
1 U - 4	8	12:31:30	0.00	0.00	59.58	58.95	59.37	59.26
1 U - 4	16	12:39:30	0.00	0.00	59.13	58.54	58.93	58.84

* LVWDT 18017 is a redundant instrument and is not included in the average.

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

Load Test Increment	Hold Time (minutes)	Time (h:m:s)	O-cell™		TOS Movement (mm)	Total Compression (mm)	Upward Movement (mm)	O-cell™ Expansion (mm)	Downward Movement (mm)
			Pressure (MPa)	Load (MN)					
1L-0	-	10:32:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1L-1	1	10:44:30	1.72	0.69	0.10	0.01	0.11	0.45	0.34
1L-1	2	10:45:30	1.72	0.69	0.10	0.01	0.11	0.45	0.34
1L-1	4	10:47:30	1.72	0.69	0.11	0.01	0.12	0.46	0.34
1L-1	8	10:51:30	1.72	0.69	0.11	0.01	0.12	0.45	0.33
1L-2	1	10:53:00	3.45	1.37	0.20	0.01	0.20	0.70	0.50
1L-2	2	10:54:00	3.45	1.37	0.21	0.01	0.22	0.72	0.50
1L-2	4	10:56:00	3.45	1.37	0.23	0.01	0.24	0.83	0.59
1L-2	8	11:00:00	3.45	1.37	0.25	0.01	0.25	0.88	0.63
1L-3	1	11:01:30	5.17	2.05	0.39	0.02	0.40	1.32	0.91
1L-3	2	11:02:30	5.17	2.05	0.41	0.02	0.43	1.42	0.99
1L-3	4	11:04:30	5.17	2.05	0.46	0.02	0.48	1.50	1.02
1L-3	8	11:08:30	5.17	2.05	0.49	0.02	0.51	1.65	1.14
1L-4	1	11:10:00	6.89	2.74	0.69	0.04	0.73	2.27	1.54
1L-4	2	11:11:00	6.89	2.74	0.74	0.04	0.78	2.46	1.68
1L-4	4	11:13:00	6.89	2.74	0.78	0.04	0.82	2.67	1.85
1L-4	8	11:17:00	6.89	2.74	0.83	0.04	0.87	2.90	2.04
1L-5	1	11:18:30	8.62	3.42	1.08	0.05	1.13	3.77	2.64
1L-5	2	11:19:30	8.62	3.42	1.16	0.06	1.21	4.05	2.83
1L-5	4	11:21:30	8.62	3.42	1.23	0.06	1.29	4.34	3.05
1L-5	8	11:25:30	8.62	3.42	1.35	0.06	1.41	4.75	3.34
1L-6	1	11:27:00	10.34	4.10	1.76	0.07	1.83	5.94	4.11
1L-6	2	11:28:00	10.34	4.10	1.88	0.07	1.96	6.32	4.37
1L-6	4	11:30:00	10.34	4.10	2.06	0.07	2.13	6.77	4.64
1L-6	8	11:34:00	10.34	4.10	2.24	0.08	2.32	7.38	5.06
1L-7	1	11:36:00	12.07	4.79	3.18	0.09	3.28	9.39	6.11
1L-7	2	11:37:00	12.07	4.79	3.38	0.09	3.47	9.85	6.38
1L-7	4	11:39:00	12.07	4.79	3.65	0.09	3.74	10.49	6.75
1L-7	8	11:43:00	12.07	4.79	3.97	0.09	4.06	11.33	7.28
1L-8	1	11:45:00	13.79	5.47	5.74	0.10	5.84	14.71	8.87
1L-8	2	11:46:00	13.79	5.47	6.09	0.10	6.19	15.26	9.07
1L-8	4	11:48:00	13.79	5.47	6.64	0.10	6.74	16.18	9.44
1L-8	8	11:52:00	13.79	5.47	7.65	0.11	7.76	17.84	10.08
1L-9	1	11:53:30	15.51	6.15	10.49	0.13	10.62	22.06	11.44
1L-9	2	11:54:30	15.51	6.15	11.72	0.13	11.85	23.73	11.88
1L-9	4	11:56:30	15.51	6.15	13.64	0.13	13.77	26.23	12.46
1L-9	8	12:00:30	15.51	6.15	16.65	0.14	16.80	29.99	13.19
1L-10	1	12:02:00	16.48	6.54	21.22	0.16	21.38	35.80	14.42
1L-10	2	12:03:00	16.48	6.54	25.29	0.17	25.46	40.44	14.99
1L-10	4	12:05:00	16.48	6.54	34.26	0.17	34.43	49.69	15.26
1L-10	8	12:09:00	16.48	6.54	52.80	0.18	52.98	68.69	15.71
1U-1	1	12:10:30	13.79	5.47	54.52	0.17	54.68	70.08	15.39
1U-1	2	12:11:30	13.79	5.47	54.54	0.17	54.71	70.07	15.37
1U-1	4	12:13:30	13.79	5.47	54.57	0.17	54.73	70.09	15.35
1U-2	1	12:15:30	6.89	2.74	53.65	0.09	53.74	67.69	13.95
1U-2	2	12:16:30	6.89	2.74	53.60	0.09	53.69	67.59	13.91
1U-2	4	12:18:30	6.89	2.74	53.54	0.09	53.63	67.48	13.85
1U-3	1	12:20:00	3.45	1.37	52.79	0.04	52.83	64.92	12.09
1U-3	2	12:21:00	3.45	1.37	52.72	0.04	52.76	64.69	11.93
1U-3	4	12:23:00	3.45	1.37	52.66	0.04	52.70	64.49	11.79
1U-4	1	12:24:30	0.00	0.00	51.57	0.00	51.57	60.67	9.10
1U-4	2	12:25:30	0.00	0.00	51.44	0.00	51.44	60.20	8.76
1U-4	4	12:27:30	0.00	0.00	51.34	0.00	51.34	59.70	8.36
1U-4	8	12:31:30	0.00	0.00	51.26	0.00	51.26	59.26	8.01
1U-4	16	12:39:30	0.00	0.00	51.15	0.00	51.15	58.84	7.69

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

Load Test Increment	Hold Time (minutes)	Time (h:m:s)	O-cell™		Upward Movement (mm)	Creep Between Hold (mm)	Downward Movement (mm)	Creep Between Hold (mm)
			Pressure (MPa)	Load (MN)				
1 L - 0	-	10:32:00	0.00	0.00	0.00		0.00	
1 L - 1	1	10:44:30	1.72	0.69	0.11		0.34	
1 L - 1	2	10:45:30	1.72	0.69	0.11	0.00	0.34	0.00
1 L - 1	4	10:47:30	1.72	0.69	0.12	0.01	0.34	0.00
1 L - 1	8	10:51:30	1.72	0.69	0.12	0.00	0.33	-0.01
1 L - 2	1	10:53:00	3.45	1.37	0.20		0.50	
1 L - 2	2	10:54:00	3.45	1.37	0.22	0.01	0.50	0.01
1 L - 2	4	10:56:00	3.45	1.37	0.24	0.03	0.59	0.09
1 L - 2	8	11:00:00	3.45	1.37	0.25	0.01	0.63	0.04
1 L - 3	1	11:01:30	5.17	2.05	0.40		0.91	
1 L - 3	2	11:02:30	5.17	2.05	0.43	0.03	0.99	0.08
1 L - 3	4	11:04:30	5.17	2.05	0.48	0.05	1.02	0.03
1 L - 3	8	11:08:30	5.17	2.05	0.51	0.03	1.14	0.12
1 L - 4	1	11:10:00	6.89	2.74	0.73		1.54	
1 L - 4	2	11:11:00	6.89	2.74	0.78	0.05	1.68	0.13
1 L - 4	4	11:13:00	6.89	2.74	0.82	0.04	1.85	0.17
1 L - 4	8	11:17:00	6.89	2.74	0.87	0.04	2.04	0.18
1 L - 5	1	11:18:30	8.62	3.42	1.13		2.64	
1 L - 5	2	11:19:30	8.62	3.42	1.21	0.08	2.83	0.19
1 L - 5	4	11:21:30	8.62	3.42	1.29	0.08	3.05	0.22
1 L - 5	8	11:25:30	8.62	3.42	1.41	0.12	3.34	0.29
1 L - 6	1	11:27:00	10.34	4.10	1.83		4.11	
1 L - 6	2	11:28:00	10.34	4.10	1.96	0.13	4.37	0.26
1 L - 6	4	11:30:00	10.34	4.10	2.13	0.17	4.64	0.28
1 L - 6	8	11:34:00	10.34	4.10	2.32	0.19	5.06	0.42
1 L - 7	1	11:36:00	12.07	4.79	3.28		6.11	
1 L - 7	2	11:37:00	12.07	4.79	3.47	0.19	6.38	0.26
1 L - 7	4	11:39:00	12.07	4.79	3.74	0.27	6.75	0.37
1 L - 7	8	11:43:00	12.07	4.79	4.06	0.32	7.28	0.52
1 L - 8	1	11:45:00	13.79	5.47	5.84		8.87	
1 L - 8	2	11:46:00	13.79	5.47	6.19	0.35	9.07	0.20
1 L - 8	4	11:48:00	13.79	5.47	6.74	0.55	9.44	0.37
1 L - 8	8	11:52:00	13.79	5.47	7.76	1.02	10.08	0.64
1 L - 9	1	11:53:30	15.51	6.15	10.62		11.44	
1 L - 9	2	11:54:30	15.51	6.15	11.85	1.23	11.88	0.43
1 L - 9	4	11:56:30	15.51	6.15	13.77	1.92	12.46	0.59
1 L - 9	8	12:00:30	15.51	6.15	16.80	3.02	13.19	0.73
1 L - 10	1	12:02:00	16.48	6.54	21.38		14.42	
1 L - 10	2	12:03:00	16.48	6.54	25.46		14.99	
1 L - 10	4	12:05:00	16.48	6.54	34.43		15.26	
1 L - 10	8	12:09:00	16.48	6.54	52.98		15.71	
1 U - 1	1	12:10:30	13.79	5.47	54.68		15.39	
1 U - 1	2	12:11:30	13.79	5.47	54.71		15.37	
1 U - 1	4	12:13:30	13.79	5.47	54.73		15.35	
1 U - 2	1	12:15:30	6.89	2.74	53.74		13.95	
1 U - 2	2	12:16:30	6.89	2.74	53.69		13.91	
1 U - 2	4	12:18:30	6.89	2.74	53.63		13.85	
1 U - 3	1	12:20:00	3.45	1.37	52.83		12.09	
1 U - 3	2	12:21:00	3.45	1.37	52.76		11.93	
1 U - 3	4	12:23:00	3.45	1.37	52.70		11.79	
1 U - 4	1	12:24:30	0.00	0.00	51.57		9.10	
1 U - 4	2	12:25:30	0.00	0.00	51.44		8.76	
1 U - 4	4	12:27:30	0.00	0.00	51.34		8.36	
1 U - 4	8	12:31:30	0.00	0.00	51.26		8.01	
1 U - 4	16	12:39:30	0.00	0.00	51.15		7.69	

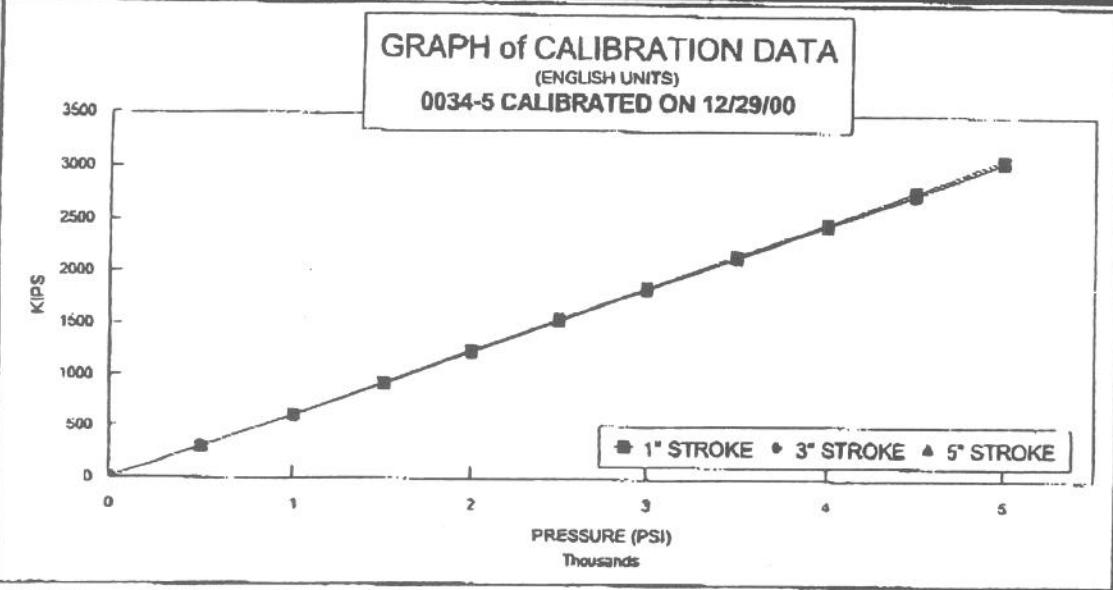
Strain Gage Readings and Loads at Levels 1 and 2
East Test Shaft - US 36 over Republican River - Republic Co., KS

Load Test Increment	Hold Time (minutes)	Time (h:m:s)	O-cell™		Level 1					Level 2				
			Pressure (MPa)	Load (MN)	20361 ($\mu\epsilon$)	20362 ($\mu\epsilon$)	20363 ($\mu\epsilon$)	20364 ($\mu\epsilon$)	Av. Load (MN)	20369 ($\mu\epsilon$)	20370 ($\mu\epsilon$)	20371 ($\mu\epsilon$)	20372 ($\mu\epsilon$)	Av. Load (MN)
1L-0	-	10:32:00	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.00
1L-1	1	10:44:30	1.72	0.69	3.0	5.0	3.6	1.2	0.26	0.9	2.3	1.7	1.1	0.12
1L-1	2	10:45:30	1.72	0.69	2.9	4.9	3.6	1.4	0.26	0.9	2.5	1.7	0.9	0.12
1L-1	4	10:47:30	1.72	0.69	3.0	4.9	3.7	1.4	0.26	0.9	2.4	1.7	0.8	0.12
1L-1	8	10:51:30	1.72	0.69	2.9	4.6	3.8	1.4	0.26	0.9	2.5	1.8	0.9	0.12
1L-2	1	10:53:00	3.45	1.37	4.8	8.0	6.4	2.2	0.43	1.2	3.0	2.1	1.5	0.16
1L-2	2	10:54:00	3.45	1.37	4.9	8.1	6.5	2.3	0.44	1.2	3.0	2.0	1.6	0.16
1L-2	4	10:56:00	3.45	1.37	5.2	9.0	6.8	2.5	0.47	1.2	3.0	2.2	1.7	0.16
1L-2	8	11:00:00	3.45	1.37	5.3	8.7	6.9	2.7	0.48	1.3	3.2	2.2	1.8	0.17
1L-3	1	11:01:30	5.17	2.05	7.7	13.6	9.9	3.8	0.70	1.8	3.9	2.6	2.2	0.21
1L-3	2	11:02:30	5.17	2.05	7.9	14.1	10.6	4.1	0.74	1.9	4.1	2.6	2.3	0.22
1L-3	4	11:04:30	5.17	2.05	8.0	14.4	10.5	3.9	0.74	2.0	4.2	2.7	2.6	0.23
1L-3	8	11:08:30	5.17	2.05	8.3	15.4	11.1	4.1	0.78	2.1	4.4	2.8	2.6	0.24
1L-4	1	11:10:00	6.89	2.74	11.4	20.4	15.5	5.9	1.07	3.1	5.9	3.6	3.4	0.32
1L-4	2	11:11:00	6.89	2.74	11.7	20.6	15.8	6.0	1.09	3.2	6.2	3.8	3.6	0.34
1L-4	4	11:13:00	6.89	2.74	12.0	21.5	16.4	6.1	1.13	3.4	6.4	4.0	3.7	0.35
1L-4	8	11:17:00	6.89	2.74	12.3	21.9	16.7	6.3	1.15	3.5	6.7	4.0	3.9	0.36
1L-5	1	11:18:30	8.62	3.42	14.6	27.3	20.9	7.6	1.42	4.4	8.2	5.6	4.9	0.47
1L-5	2	11:19:30	8.62	3.42	14.7	27.9	21.3	7.8	1.44	4.6	8.6	6.0	5.1	0.49
1L-5	4	11:21:30	8.62	3.42	15.0	28.2	21.4	7.8	1.46	4.6	8.7	6.1	5.2	0.50
1L-5	8	11:25:30	8.62	3.42	15.4	29.1	22.2	8.0	1.50	4.9	9.1	6.6	5.4	0.52
1L-6	1	11:27:00	10.34	4.10	17.8	34.1	25.8	9.0	1.74	5.6	10.8	8.5	6.6	0.63
1L-6	2	11:28:00	10.34	4.10	17.9	34.5	26.3	9.1	1.77	5.7	11.2	9.0	6.9	0.66
1L-6	4	11:30:00	10.34	4.10	18.1	35.1	26.4	9.0	1.78	5.7	11.5	9.4	7.0	0.68
1L-6	8	11:34:00	10.34	4.10	18.6	36.1	27.1	9.1	1.83	5.9	11.9	10.0	7.2	0.71
1L-7	1	11:36:00	12.07	4.79	21.5	41.1	30.2	10.3	2.07	6.6	13.8	12.9	8.4	0.84
1L-7	2	11:37:00	12.07	4.79	21.9	41.2	30.1	10.3	2.08	6.6	14.0	13.3	8.6	0.86
1L-7	4	11:39:00	12.07	4.79	22.0	41.9	30.3	10.2	2.10	6.6	14.4	14.1	8.7	0.88
1L-7	8	11:43:00	12.07	4.79	21.8	42.7	30.5	10.0	2.11	6.7	14.7	14.7	9.0	0.91
1L-8	1	11:45:00	13.79	5.47	25.6	48.9	33.8	10.6	2.39	7.2	17.1	18.5	10.3	1.07
1L-8	2	11:46:00	13.79	5.47	25.7	49.3	33.9	10.8	2.41	7.2	17.4	18.9	10.3	1.08
1L-8	4	11:48:00	13.79	5.47	25.9	49.9	33.9	11.0	2.43	7.3	17.8	19.7	10.5	1.11
1L-8	8	11:52:00	13.79	5.47	26.0	49.2	35.4	12.6	2.48	7.4	18.3	21.7	10.9	1.17
1L-9	1	11:53:30	15.51	6.15	27.7	56.7	40.0	12.6	2.76	7.5	19.8	28.5	12.1	1.37
1L-9	2	11:54:30	15.51	6.15	27.6	57.9	41.4	12.7	2.81	7.2	19.9	27.9	12.0	1.35
1L-9	4	11:56:30	15.51	6.15	26.4	59.4	43.5	13.0	2.86	7.4	20.1	28.3	12.4	1.37
1L-9	8	12:00:30	15.51	6.15	25.7	60.3	45.7	13.5	2.92	7.2	19.9	29.2	12.6	1.39
1L-10	1	12:02:00	16.48	6.54	26.6	67.0	51.8	13.9	3.21	6.5	20.7	33.2	13.2	1.48
1L-10	2	12:03:00	16.48	6.54	25.7	69.4	54.7	14.0	3.30	6.1	21.1	34.1	12.9	1.49
1L-10	4	12:05:00	16.48	6.54	21.6	70.6	58.5	13.2	3.30	4.7	21.3	32.8	11.1	1.41
1L-10	8	12:09:00	16.48	6.54	18.3	72.3	63.6	12.9	3.36	3.4	17.1	32.5	9.4	1.26
1U-1	1	12:10:30	13.79	5.47	14.0	69.2	61.6	9.5	3.11	1.7	16.1	30.8	8.7	1.15
1U-1	2	12:11:30	13.79	5.47	13.6	68.4	61.2	9.4	3.07	1.6	16.0	30.7	8.8	1.15
1U-1	4	12:13:30	13.79	5.47	13.6	66.7	60.3	9.8	3.03	1.4	15.7	30.5	8.9	1.14
1U-2	1	12:15:30	6.89	2.74	0.7	45.6	43.8	1.5	1.84	-4.1	8.8	22.4	4.3	0.63
1U-2	2	12:16:30	6.89	2.74	0.6	44.7	43.4	1.6	1.82	-4.0	8.5	22.0	4.3	0.62
1U-2	4	12:18:30	6.89	2.74	0.5	44.3	43.1	1.8	1.81	-4.0	8.5	21.8	4.4	0.61
1U-3	1	12:20:00	3.45	1.37	-6.3	29.3	32.1	-1.7	1.07	-7.3	4.3	17.1	1.8	0.32
1U-3	2	12:21:00	3.45	1.37	-6.3	29.0	32.0	-1.8	1.07	-7.3	4.2	16.9	1.7	0.31
1U-3	4	12:23:00	3.45	1.37	-6.2	28.8	32.3	-1.2	1.08	-7.4	4.1	16.8	1.9	0.31
1U-4	1	12:24:30	0.00	0.00	-8.6	7.8	16.2	-0.2	0.30	-9.2	-1.0	11.1	-0.1	0.02
1U-4	2	12:25:30	0.00	0.00	-8.5	7.3	15.9	0.4	0.30	-9.2	-1.0	11.0	-0.2	0.01
1U-4	4	12:27:30	0.00	0.00	-8.2	6.9	15.7	0.5	0.30	-9.1	-1.0	11.0	0.0	0.02
1U-4	8	12:31:30	0.00	0.00	-8.1	7.0	15.6	1.3	0.32	-9.1	-1.1	10.8	0.1	0.02
1U-4	16	12:39:30	0.00	0.00	-7.8	6.0	15.3	1.6	0.30	-9.1	-1.6	10.6	0.3	0.00

APPENDIX B

O-CELL™ AND INSTRUMENTATION CALIBRATION SHEETS





STROKE: 1 INCH 3 INCH 5 INCH

34" O-CELL, SERIAL # 0034-5

PRESSURE PSI	LOAD KIPS	LOAD KIPS	LOAD KIPS
0	0	0	0
500	302	300	305
1000	614	608	608
1500	938	927	918
2000	1247	1233	1224
2500	1555	1542	1530
3000	1858	1846	1836
3500	2167	2152	2139
4000	2473	2457	2446
4500	2781	2767	2747
5000	3089	3067	3052

LOAD CONVERSION FORMULA

$$\text{LOAD} = \text{PRESSURE} * 0.6146 + (0.67)$$

(KIPS) (PSI)

Regression Output:

Constant	0.673
X Coefficient	0.615
R Squared	1.000
No. of Observations	30
Degrees of Freedom	28
Std Err of Y Est	11.290
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.
*AE & FC JOB NO.: 1806
*CUSTOMER P.O.NO.: LT-8718

*CONTRACTOR: MIDWEST FOUNDATION
*JOB LOCATION: TOPEKA, KS
*DATED: 03/08/01

SERVICE ENGINEER:

GilPal

DATE: 3/15/01



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

Vibrating Wire Displacement Transducer Calibration Report

Model Number: 4450-3-6Range: 6"Serial Number: 18015Mfg. Number: 01-222Customer: Loadtest, Inc.Temperature: 23.9 °CCust. I.D. #: n/aCal. Std. Control #(s): 124, 249, 406, 524, 529Job Number: 16668Date of Calibration: March 05, 2001Technician: KDB

Displacement (inches)	GK-401 Reading Position B				
	Cycle 1	Cycle 2	Average	Change	% Linearity
0.000	2880	2878	2879		-0.05
1.200	4111	4108	4110	1231	-0.01
2.400	5342	5340	5341	1232	0.05
3.600	6569	6569	6569	1228	0.06
4.800	7796	7793	7795	1226	0.02
6.000	9017	9017	9017	1223	-0.07

Calibration Factor (C): 0.0009774 (Inches/Digit)Regression Zero: 2882

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B":* 5479Date: March 13, 2001

or

Position "F":* Temperature: 25.9 °C

Wiring Code:

Red and Black: Gage

White and Green: Thermistor

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

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

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

Vibrating Wire Displacement Transducer Calibration Report

Model Number: 4450-3-6Range: 6"Serial Number: 18016Mfg. Number: 01-223Customer: Loadtest, Inc.Temperature: 23.9 °CCust. I.D. #: n/aCal. Std. Control #(s): 124, 249, 406, 524, 529Job Number: 16668Date of Calibration: March 05, 2001Technician: KOB

Displacement (inches)	GK-401 Reading Position B				% Linearity
	Cycle 1	Cycle 2	Average	Change	
0.000	2847	2844	2846		-0.21
1.200	4094	4092	4093	1248	0.10
2.400	5325	5323	5324	1231	0.14
3.600	6553	6550	6552	1228	0.12
4.800	7774	7773	7774	1222	0.01
6.000	8993	8991	8992	1219	-0.16

Calibration Factor (C): 0.0009767 (Inches/Digit)Regression Zero: 2858

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B":* 5519Date: March 13, 2001

or

Position "F":* Temperature: 23.8 °CWiring 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.

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

Vibrating Wire Displacement Transducer Calibration Report

Model Number: 4450-3-6Range: 6"Serial Number: 18017Mfg. Number: 01-224Customer: Loadtest, Inc.Temperature: 23.9 °CCust. I.D. #: n/aCal. Std. Control #(s): 124, 249, 406, 524, 529Job Number: 16668Date of Calibration: March 05, 2001Technician: KOB

Displacement (inches)	GK-401 Reading Position B				
	Cycle 1	Cycle 2	Average	Change	% Linearity
0.000	2798	2794	2796		-0.21
1.200	4046	4042	4044	1248	0.08
2.400	5281	5279	5280	1236	0.17
3.600	6507	6507	6507	1227	0.11
4.800	7732	7730	7731	1224	0.01
6.000	8951	8951	8951	1220	-0.16

Calibration Factor (C): 0.0009753 (Inches/Digit)Regression Zero: 2809

Refer to manual for temperature correction information.

Function Test at Shipment (GK-401 Reading)

Position "B":* 5488 Date: March 13, 2001

or

Position "F":* Temperature: 24.5 °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.

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

Sister Bar Calibration Report

Model Number : 4911-4Calibration Date: March 13, 2001Serial Number: 20361Cal. Std. Control Numbers: 85888-1, 398Customer: Loadtest, Inc.Cable Length: 40'Job Number: 16668Factory Zero Reading: 6926Cust. I.D. #: n/aRegression Zero: 6923Prestress: 35,000 psiTechnician: KOBTemperature: 22.1 °C

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6973	6976	6975		
1,500	7660	7663	7662	687	-0.02
3,000	8400	8400	8400	739	-0.04
4,500	9142	9148	9145	745	0.16
6,000	9881	9877	9879	734	-0.02
100	6978				

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

Gage Factor:0.344 Microstrain/Digit (GK-401 Pos. "B")**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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

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

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

Sister Bar Calibration Report

Model Number : 4911-4Calibration Date: March 13, 2001Serial Number: 20362Cal. Std. Control Numbers: 85888-1, 398Customer: Loadtest, Inc.Cable Length: 40'Job Number: 16668Factory Zero Reading: 6850Cust. I.D. #: n/aRegression Zero: 6856Prestress: 35,000 psiTechnician: KOBTemperature: 22.2 °C

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6910	6914	6912		
1,500	7595	7598	7597	685	-0.17
3,000	8341	8347	8344	748	-0.10
4,500	9091	9098	9095	751	0.07
6,000	9839	9842	9841	746	0.09
100	6915				

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

Gage Factor:0.342 Microstrain/Digit (GK-401 Pos."B")**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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

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

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

Sister Bar Calibration Report

Model Number : 4911-4Calibration Date: March 13, 2001Serial Number: 20363Cal. Std. Control Numbers: 85888-1, 398Customer: Loadtest, Inc.Cable Length: 40'Job Number: 16668Factory Zero Reading: 6962Cust. I.D. #: n/aRegression Zero: 6973Prestress: 35,000 psiTechnician: KDBTemperature: 22.2 °C

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7033	7031	7032		
1,500	7700	7700	7700	668	-0.34
3,000	8443	8445	8444	744	-0.10
4,500	9187	9186	9187	743	0.09
6,000	9926	9922	9924	738	0.11
100	7032				

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

Gage Factor:0.344 Microstrain/Digit (GK-401 Pos. "B")**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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

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

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

Sister Bar Calibration Report

Model Number : 4911-4Calibration Date: March 13, 2001Serial Number: 20364Cal. Std. Control Numbers: 85888-1, 398Customer: Loadtest, Inc.Cable Length: 40'Job Number: 16668Factory Zero Reading: 7090Cust. I.D. #: n/aRegression Zero: 7091Prestress: 35,000 psiTechnician: KOBTemperature: 22.2 °C

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7142	7149	7146		
1,500	7826	7828	7827	682	-0.17
3,000	8569	8575	8572	745	-0.03
4,500	9321	9318	9320	748	0.19
6,000	10052	10057	10055	735	-0.01
100	7151				

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

Gage Factor:0.343 Microstrain/Digit (GK-401 Pos. "B")**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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

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

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

Sister Bar Calibration Report

Model Number : 4911-4Calibration Date: March 13, 2001Serial Number: 20369Cal. Std. Control Numbers: 85888-1, 398Customer: Loadtest, Inc.Cable Length: 35'Job Number: 16668Factory Zero Reading: 6729Cust. I.D. #: n/aRegression Zero: 6721Prestress: 35,000 psiTechnician: KOBTemperature: 22.8 °C

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6781	6784	6783		
1,500	7453	7455	7454	672	-0.30
3,000	8198	8197	8198	744	-0.24
4,500	8953	8945	8949	752	0.09
6,000	9692	9696	9694	745	0.19
100	6784				

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

Gage Factor:0.343 Microstrain/Digit (GK-401 Pos."B")**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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

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

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

Sister Bar Calibration Report

Model Number : 4911-4Calibration Date: March 13, 2001Serial Number: 20370Cal. Std. Control Numbers: 85888-1, 398Customer: Loadtest, Inc.Cable Length: 35'Job Number: 16668Factory Zero Reading: 6938Cust. I.D. #: n/aRegression Zero: 6956Prestress: 35,000 psiTechnician: KQBTemperature: 22.8 °C

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7013	7012	7013		
1,500	7699	7700	7700	687	-0.28
3,000	8462	8458	8460	761	0.00
4,500	9215	9211	9213	753	0.03
6,000	9966	9965	9966	753	0.05
100	7013				

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

Gage Factor:0.339 Microstrain/Digit (GK-401 Pos."B")**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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

Sister Bar Calibration Report

Model Number : 4911-4Calibration Date: March 13, 2001Serial Number: 20371Cal. Std. Control Numbers: 85888-1, 398Customer: Loadtest, Inc.Cable Length: 35'Job Number: 16668Factory Zero Reading: 6777Cust. I.D. #: n/aRegression Zero: 6787Prestress: 35,000 psiTechnician: KOBTemperature: 22.8 °C

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6848	6840	6844		
1,500	7522	7515	7519	675	-0.24
3,000	8258	8260	8259	741	-0.18
4,500	9006	9006	9006	747	0.10
6,000	9747	9741	9744	738	0.08
100	6841				

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

Gage Factor:0.344 Microstrain/Digit (GK-401 Pos."B")**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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

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

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

Sister Bar Calibration Report

Model Number : 4911-4Calibration Date: March 13, 2001Serial Number: 20372Cal. Std. Control Numbers: 85888-1, 398Customer: Loadtest, Inc.Cable Length: 35'Job Number: 16668Factory Zero Reading: 6715Cust. I.D. #: n/aRegression Zero: 6746Prestress: 35,000 psiTechnician: KOBTemperature: 23.3 °C

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	6802	6799	6801		
1,500	7472	7468	7470	670	-0.23
3,000	8208	8203	8206	736	-0.07
4,500	8945	8938	8942	736	0.11
6,000	9675	9664	9670	728	0.02
100	6801				

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

Gage Factor:0.347 Microstrain/Digit (GK-401 Pos."B")**Calculated Strain = Gage Factor(Current Reading - Zero Reading)**

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

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

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APPENDIX C

CONSTRUCTION OF THE EQUIVALENT TOP-LOADED LOAD-SETTLEMENT CURVE



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

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

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

1. The end bearing load-movement curve in a top-loaded shaft has the same loads for a given movement as the net (subtract buoyant weight of pile above O-cell™) end bearing load-movement curve developed by the bottom of the O-cell™ when placed at or near the bottom of the shaft.
2. The side shear load-movement curve in a top-loaded shaft has the same net shear, multiplied by an adjustment factor 'F', for a given downward movement as occurred in the O-cell™ test for that same movement at the top of the cell in the upward direction. The same applies to the upward movement in a top-loaded tension test. Unless noted otherwise, we use the following adjustment factors: (a) F = 1.00 in all rock sockets and for primarily cohesive soils in compression (b) F = 0.95 in primarily cohesionless soils (c) F = 0.80 for all soils in top load tension tests.
3. We initially assume the pile behaves as a rigid body, but include the elastic compressions that are part of the movement data obtained from an O-cell™ test (OLT). Using this assumption, we construct an equivalent top-load test (TLT) movement curve by the method described below in Procedure Part I. We then use the following Procedure Part II to correct for the effects of the additional elastic compressions in a TLT.
4. Consider the case with the O-cell™, or the bottom O-cell™ of more than one level of cells, placed some distance above the bottom of the shaft. We assume the part of the shaft below the cell, now top-loaded, has the same load-movement behavior as when top-loading the entire shaft. For this case the subsequent "end bearing movement curve" refers to the movement of the entire length of shaft below the cell

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

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



first converting gross to net loads. For our conservative reconstruction of the top loaded settlement curve we first convert both of the O-cell components to net load.

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

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

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

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

The attached analysis p. 6 gives the equations for the elastic compressions that occur in the OLT with one or two levels of O-cells™. Analysis p. 7 gives the equations for the elastic compressions that occur in the equivalent TLT. Both sets of equations do not include the elastic compression below the O-cell™ because the same compression takes place in both the OLT and the TLT. This is equivalent to taking $L_3 = 0$. Subtracting the OLT from the TLT compression gives the desired additional elastic



compression at the top of the TLT. We then add the additional elastic compression to the 'rigid' equivalent curve obtained from Part I to obtain the final, corrected equivalent load-settlement curve for the TLT on the same pile as the actual OLT.

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

The analysis p. 8 provides an example of calculated results in English units on a hypothetical 1-stage, single level OLT using the simplified method in Part II with the 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 $\frac{1}{4}$ 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



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

Figure A

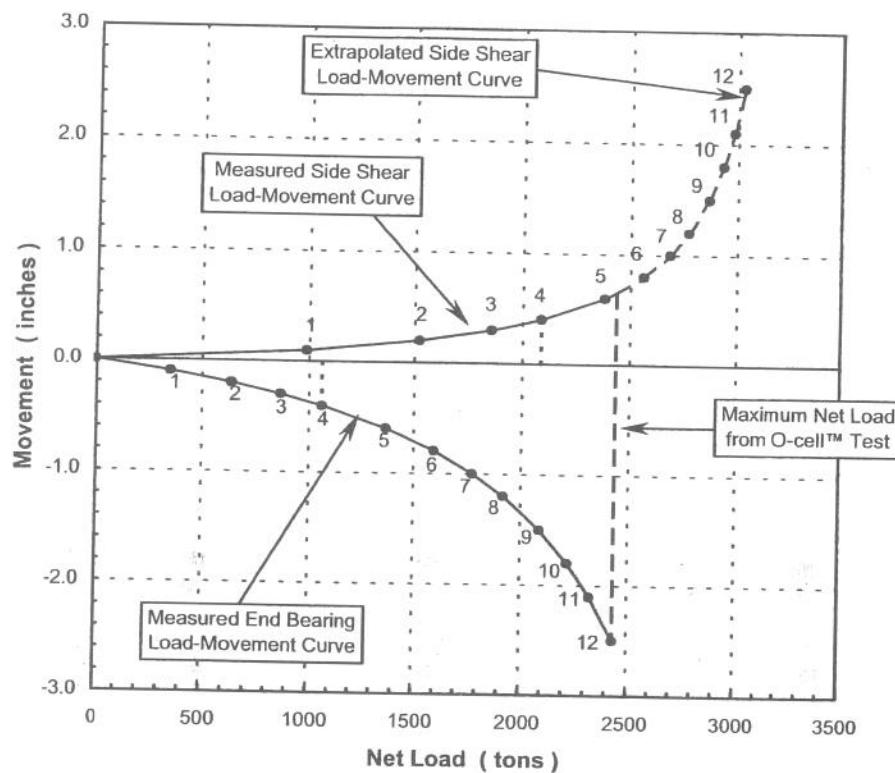
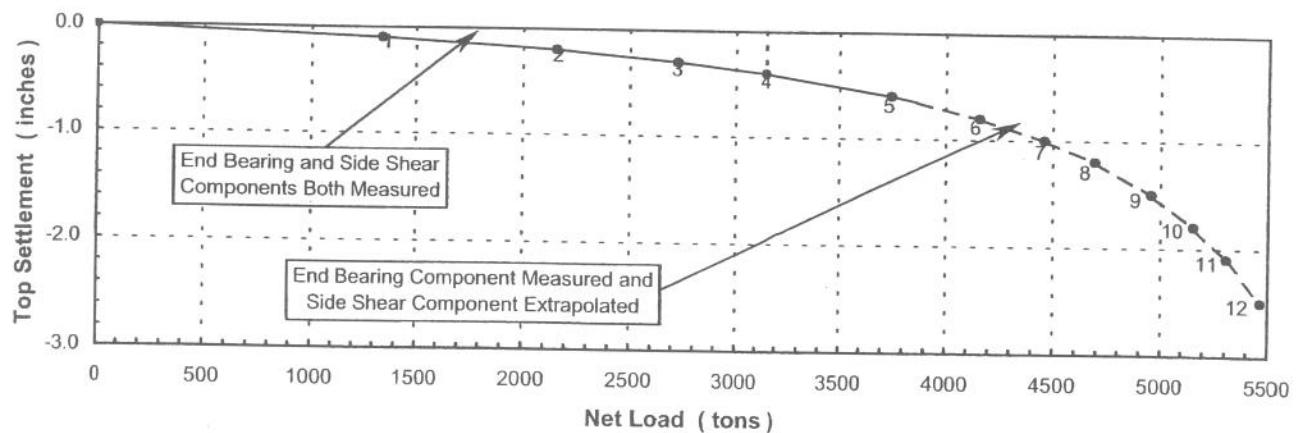
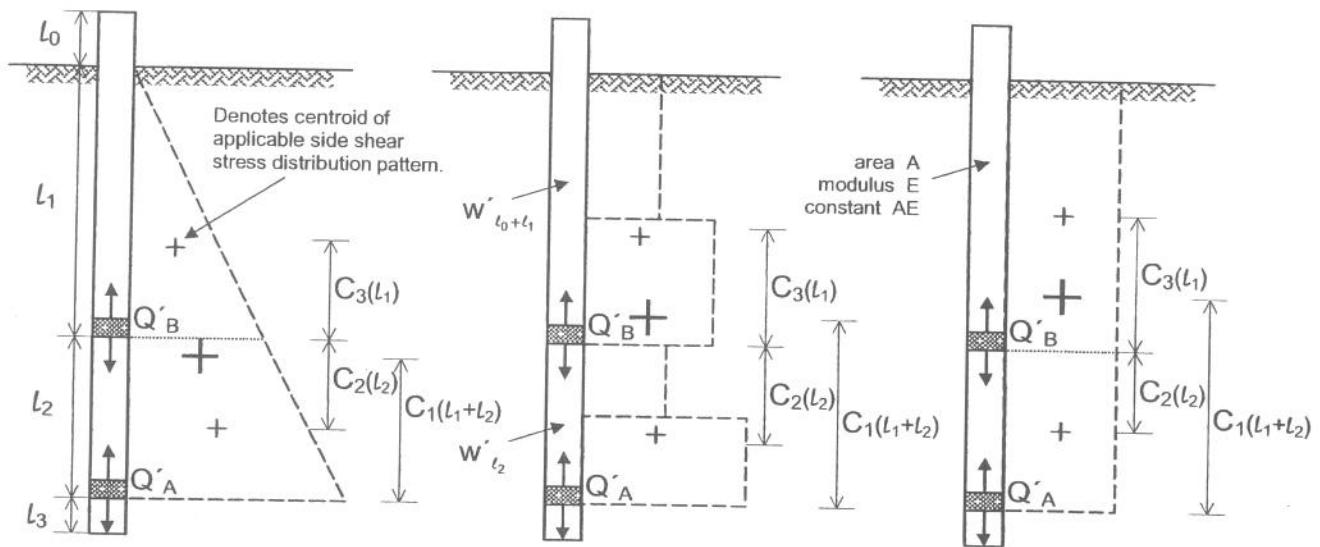


Figure B



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:

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

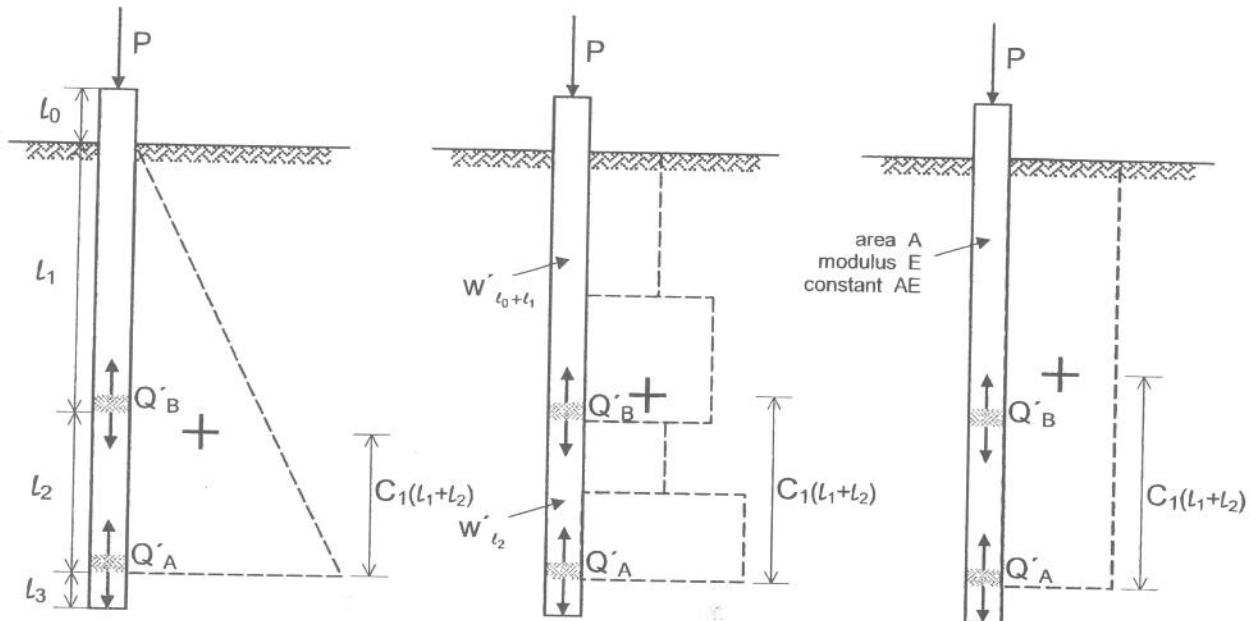
$$Q'_{\uparrow B} = Q_{\uparrow B} - W'_{l_0+l_1}$$

$$Q'_{\downarrow B} = Q_{\downarrow B} + W'_{l_2}$$

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

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

Net and Equivalent Loads:

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

$$P_{\text{single}} = Q'_{\downarrow A} + Q'_{\uparrow A}$$

$$P_{\text{multi}} = Q'_{\downarrow A} + Q'_{\uparrow B} + Q'_{\downarrow B}$$

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

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

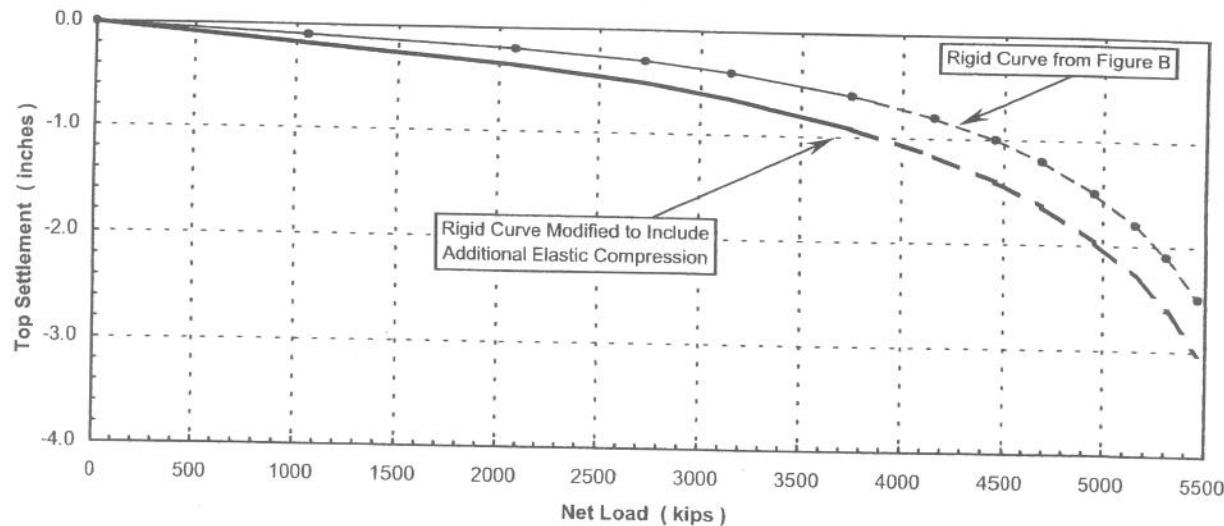
Given:

$$\begin{aligned}C_1 &= 0.441 \\AE &= 3820000 \text{ kips} \text{ (assumed constant throughout test)} \\l_0 &= 5.9 \text{ ft} \\l_1 &= 48.2 \text{ ft} \text{ (embedded length of shaft above O-cell™)} \\l_2 &= 0.0 \text{ ft} \\l_3 &= 0.0 \text{ ft}\end{aligned}$$

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)

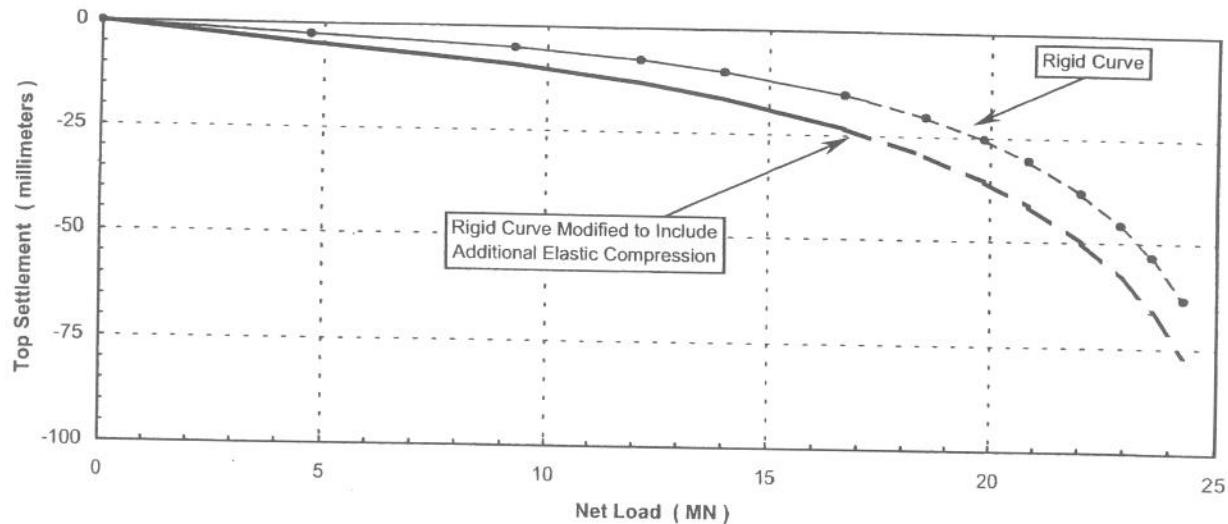
Given:

$$\begin{aligned}
 C_1 &= 0.441 \\
 AE &= 17000 \text{ MN (assumed constant throughout test)} \\
 l_0 &= 1.80 \text{ m} \\
 l_1 &= 14.69 \text{ m (embedded length of shaft above O-cell™)} \\
 l_2 &= 0.00 \text{ m} \\
 l_3 &= 0.00 \text{ m}
 \end{aligned}$$

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

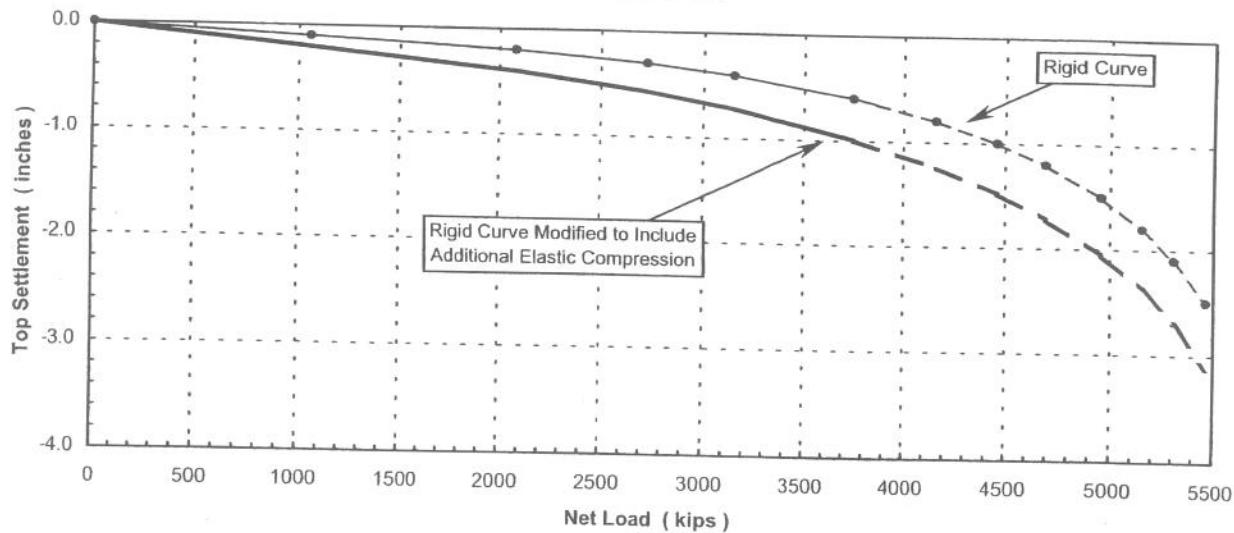
Given:

$$\begin{aligned}
 C_1 &= 0.441 \\
 C_2 &= 0.579 \\
 C_3 &= 0.396 \\
 AE &= 3820000 \text{ kips (assumed constant throughout test)} \\
 l_0 &= 5.9 \text{ ft} \\
 l_1 &= 30.0 \text{ ft (embedded length of shaft above mid-cell)} \\
 l_2 &= 18.2 \text{ ft (embedded length of shaft between O-cells™)} \\
 l_3 &= 0.0 \text{ ft}
 \end{aligned}$$

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

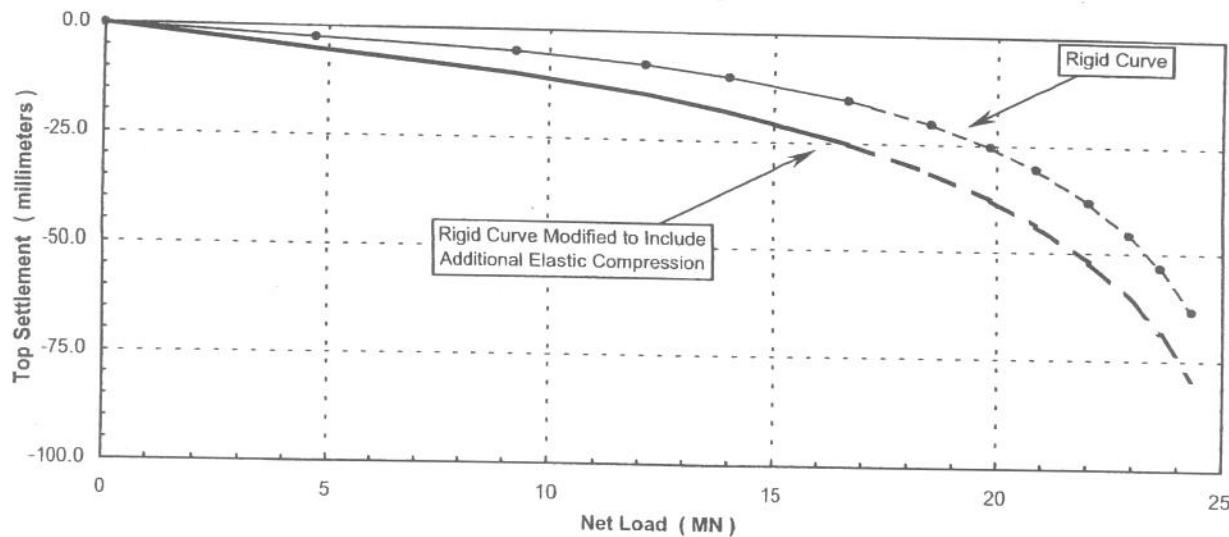
Given:

$$\begin{aligned}
 C_1 &= 0.441 \\
 C_2 &= 0.579 \\
 C_3 &= 0.396 \\
 AE &= 17000 \text{ MN} \text{ (assumed constant throughout test)} \\
 l_0 &= 1.80 \text{ m} \\
 l_1 &= 9.14 \text{ m (embedded length of shaft above mid-cell)} \\
 l_2 &= 5.55 \text{ m (embedded length of shaft between O-cells™)} \\
 l_3 &= 0.00 \text{ m}
 \end{aligned}$$

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 LOADING



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

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

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

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

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

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

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



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

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

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

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

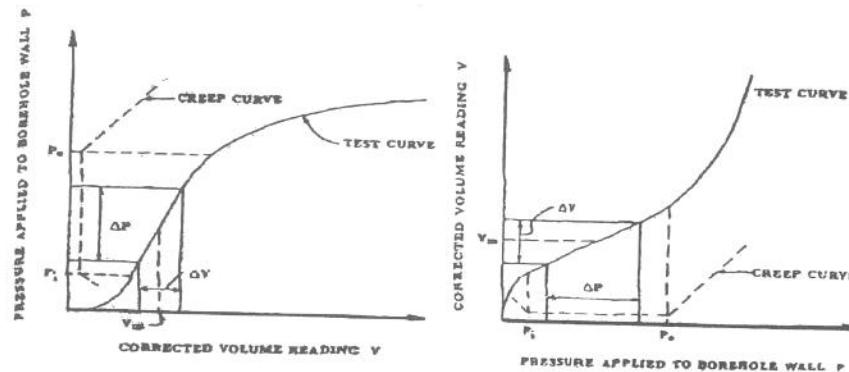


FIG. 8 Pressuremeter Test Curves for Procedure A

References

- Housel, W.S. (1959), "Dynamic & Static Resistance of Cohesive Soils", ASTM STP 254, pp. 22-23.
- Stoll, M.U.W. (1961, Discussion, Proc. 5th ICSMFE, Paris, Vol. III, pp. 279-281.
- Bourges, F. and Levillian, J-P (1988), "force portante des rideaux plans metalliques charges verticalmement," Bull. No. 158, Nov.-Dec., des laboratoires des ponts et chaussees, p. 24.
- Fellenius, Bengt H. (1996), Basics of Foundation Design, BiTech Publishers Ltd., p.79.

APPENDIX E

SOIL BORING LOG





KANSAS DEPARTMENT OF TRANSPORTATION

RTE./CO.	US-36/Republic Co	SOUNDING NO. CD 1-2	SHEET 1 OF 2
BRIDGE STA	3-715.830	PROJ.NO. 36-79 K-5043-01	BRIDGE NO. 36-79-07.60(XXX)
SITE NAME	US-36 over Republican River		
GEOLOGIST	J Geist	SCALE 1:100 (10mm=1m)	DATE 5/5/00
DRILLER	B Bergman	RIG TYPE Mobile B51	TOP HOLE ELEV. 437.763
GW ELEV.	H 435.23	TOTAL DEPTH 17.77	M/B ELEV. 431.053

BIT TYPE	GEOLOGIC NAME	STRATIGRAPHIC COLUMN	DEPTH	ELEVATION	CLASSIFICATION OF MATERIALS DESCRIPTION AND REMARKS	STANDARD PENETRATION TEST (SPT)	
						UNCONFINED COMPRESSION	N COUNT ELEVATION
8" Hollow Stem Augers	Alluvium		122	437	Sand, very fine to fine grained, scattered coarse, brown, very silty. 436.543	809	436.85
			213	436	Silt, dark gray, very fine grained sand 435.633		
				435	Sand, light brown to gray-brown, medium to coarse grained, silty.		
				434			
				433			
				432			
				431	431.053		
NN Diamond	NN Carbide	Graneros Shale Formation	6.71		Shale, gray to dark gray, some sand, lumpy with lumpy seams, finely laminated.	1171.5	429.25
			1			12.2	
			2			4396.28	427.92
			3			1043.6	427.61
			4	13.50		398.5	427.06
			5	14.20		220.4	426.23
					424.263	726.0	425.67
					423.563	871.1	424.95
						198.9	423.93
					Shale, dark gray, sandy, few lenses, pyrite	364.9	423.13



KANSAS DEPARTMENT OF TRANSPORTATION

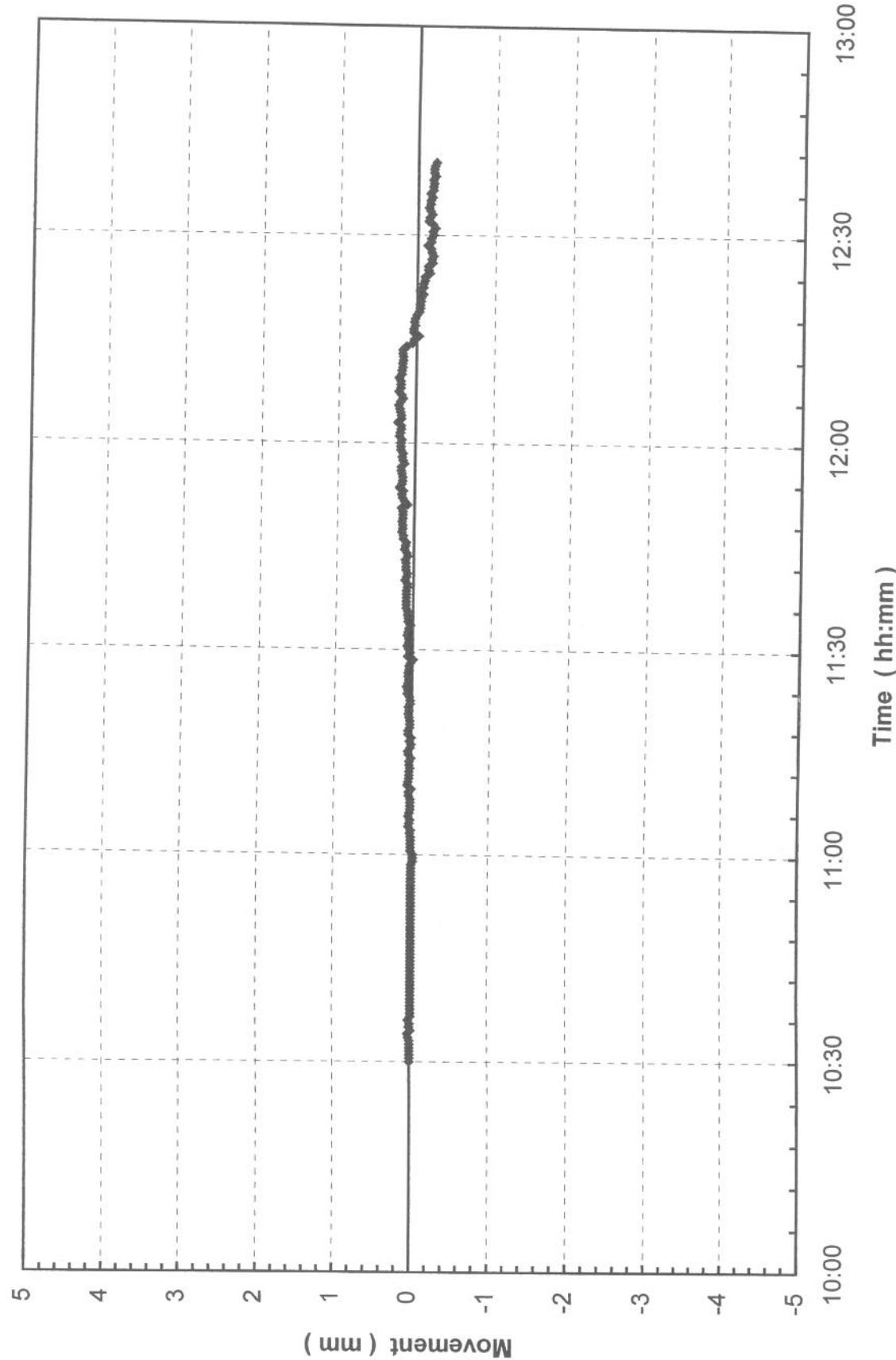
RTE/CO.	US-36/Republic Co	SOUNDING NO.	CD 1-2	SHEET 2 OF 2
BRIDGE STA	3-715.830	PROJ.NO.	36-79 K-5043-01	BRIDGE NO. 36-79-07.60(XXX)
SITE NAME	US-36 over Republican River			HOLE STA 3-8962.49 R1

APPENDIX F

REFERENCE BEAM MONITORING



Reference Beam Monitoring
East Test Shaft - US 36 over Republican River - Republic Co., KS



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APPENDIX G

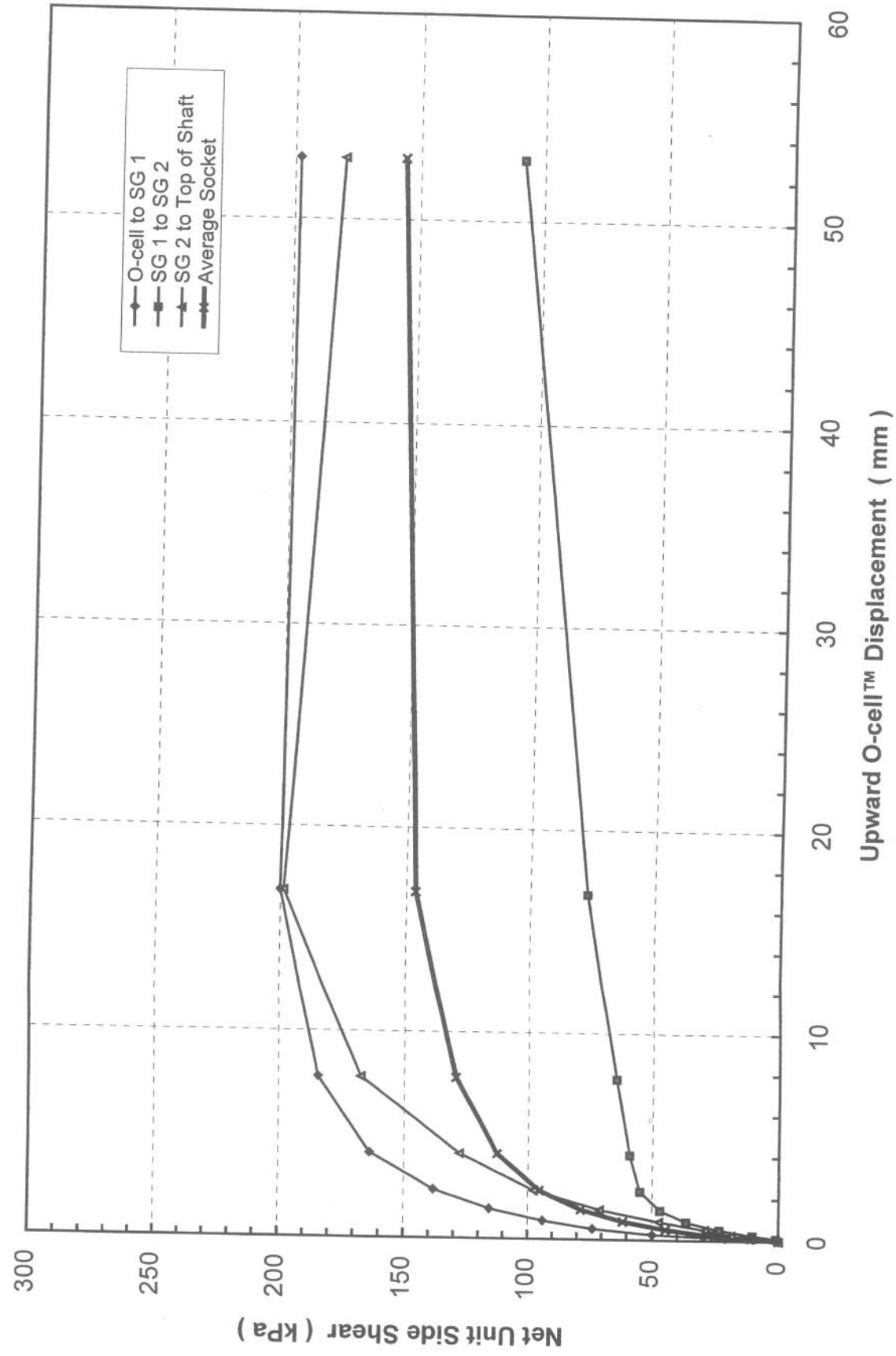
NET UNIT SHEAR AND UNIT END BEARING CURVES



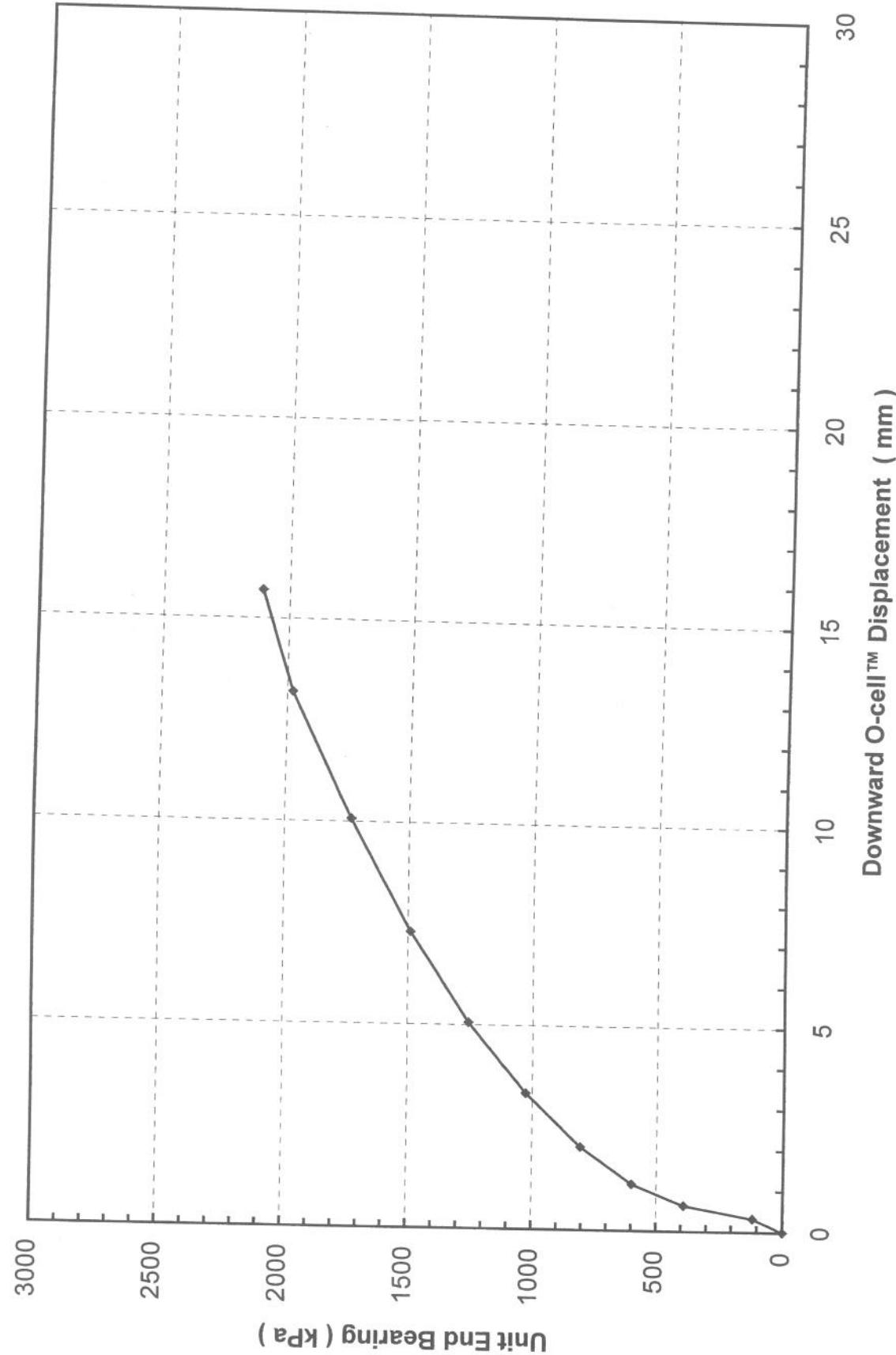
Appendix G - Figure 1

LOADTEST, Inc. Project No. LT-8718-2

Net Unit Side Shear Curves East Test Shaft - US 36 over Republican River - Republic Co., KS



Unit End Bearing Curve
East Test Shaft - US 36 over Republican River - Republic Co., KS



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