



## LETTER OF TRANSMITTAL

**To:** MnDOT  
248 125th NE  
Thief River Falls, MN 56701  
**Phone:** 218-683-8003  
**Fax:** \_\_\_\_\_  
**Attention:** Shawn Groven/Earl Warren-MTO

**Date:** 11/27/2018

**Re:** SP 3905-09  
Lunda Project #10756900  
Baudette Border Crossing

**Transmittal #:** L040

**We are forwarding to you:**

<input type="checkbox"/> Estimates	<input type="checkbox"/> Proposals	<input checked="" type="checkbox"/> Reports
<input type="checkbox"/> Plans	<input type="checkbox"/> Schedule	<input type="checkbox"/> Schedule
<input type="checkbox"/> Shop Drawings	<input type="checkbox"/> Samples	<input type="checkbox"/> Cost Estimates
<input type="checkbox"/> Copy of Phone Memo	<input type="checkbox"/> Change Order	<input type="checkbox"/> Other - RFI

Copies	Date	Description
1	26-Nov-18	AFT Report - Bi-Directional Cell & Caliper Report

**These are transmitted as checked below:**

<input checked="" type="checkbox"/> For Approval	<input type="checkbox"/> Resubmit	<input type="checkbox"/> No exceptions taken
<input type="checkbox"/> For Acceptance	<input type="checkbox"/> Submit	<input type="checkbox"/> Make corrections noted
<input type="checkbox"/> As requested	<input type="checkbox"/> Return	<input type="checkbox"/> Amend and resubmit
<input type="checkbox"/> For review	<input type="checkbox"/> Copies	<input type="checkbox"/> For Construction

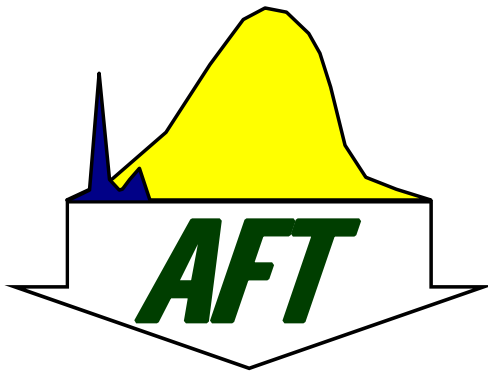
**Please note:**

\_\_\_\_\_  
\_\_\_\_\_

**Cc:** Shawn Groven - MnDOT  
Earl Warren - MTO  
Corey Johnson - MnDOT

**By:** Cory Spanier- Lunda Construction Company

# Applied Foundation Testing



November 26, 2018

**Final Data Report of AFT-Cell™  
Bi-Directional Static Load Testing  
Rainy River Bridge  
Baudette, Minnesota  
MNDOT Project No.: 3950-09  
AFT Project No.: 518053**

**Authored By:**

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**Andrew Best**  
Staff Geotechnical Engineer

**For:**  
**Allie Brady**  
Project Manager



**14000 Veit Place  
Rogers, MN 55374  
Direct: 763-428-9558  
Cell: 612-221-1421  
Fax: 763-428-8348**

**Reviewed By:**

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**Donald T. Robertson, P.E.**  
Principal Geotechnical Engineer



## INTRODUCTION

The construction of the Rainy River Bridge is part of an effort by the Minnesota Department of Transportation to connect Baudette, Minnesota, United States to Rainy River, Ontario, Canada. As part of the project a bi-directional axial load testing program was performed on one test shaft. The test shaft was 96 inches in diameter with an overall length of approximately 115.0 feet. The maximum bi-directional test load was specified at 16,000 kips. The shaft was instrumented with five levels of strain gages.

A single level cell assembly consisting of three bi-directional embedded jacks was installed with the break in the cell approximately 11 feet above the shaft tip at Elevation +961.8 feet. Five levels of strain gages with four gages per level were also included within the shaft to measure load distribution. In addition to the strain instrumentation, four embedded LVWDTs (Linear Vibrating Wire Displacement Transducers, Geokon Model 4450) were installed to obtain displacement data at the cell location and two telltales were installed at the top of the cell. Schematic drawings of the as-built instrumentation locations are included in [Appendix A](#).

The test shaft was load tested on November 8, 2018 with loading steps in accordance with the project documents and ASTM D8169 "*Standard Test Methods for Deep Foundations Under Bi-Directional Static Axial Compressive Load*", Procedure A. The maximum unidirectional applied load was 7,382 kips with 0.22 inches of upward displacement and 2.80 inches of downward displacement. After accounting for the approximate shaft weight above the AFT-Cell™ of 454 kips, the maximum applied bi-directional load was 14,310 kips. Geotechnical ultimate resistance was not observed in the shaft sections above or below the cell assembly during the test.

Veit was the drilled shaft foundation contractor. Soil information was provided in the project plans by the Minnesota Department of Transportation. Applied Foundation Testing (AFT) provided specialty load testing services under agreement with Veit. Field instrumentation of the test shaft was performed by Ryan Wendlandt and Andrew Best. Performance of the load test was conducted by Donald T. Robertson, P.E., Michael Chan and Andrew Best. Analysis of the test data was performed by Donald T. Robertson, P.E., Jordan Nelson, P.E. and Andrew Best.

## GENERALIZED SOIL CONDITIONS

The Minnesota DOT provided the subsurface information for the project on sheet number 120 of the project plans. The plan sheet associated with the test shaft is provided in [Appendix B](#). Descriptions of the subsurface conditions encountered are presented on the plan sheet, while a summary of the soil conditions at the test shaft location is given below.

Based on the MNDOT Drilled Shaft Record, we understand the ground surface elevation is approximately +1039.0 feet. The plan sheet breaks the soils into four different zones. [Table 1](#) summarizes the soil information provided to AFT.



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Final Data Report of Bi-Directional Static Load Testing  
Rainy River Bridge - Baudette, Minnesota

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**Table 1. Soil Summary**

Zone	Elevation	Soil Description
A	+1059.0 to +1039.0	Water
B	+1039.0 to +1031.0	Poorly graded sand, coarse to fine grained, brown to gray, wet to water bearing, very loose
C	+1031.0 to +1016.0	Lean clay with a trace of gravel, little to some sand, gray, wet, medium to soft
D	+1016.0 to +1003.0	Silty sand with a trace to a little gravel and a trace of clay, gray, moist to wet, slightly plastic, very dense
E	+1003.0 and Deeper	Boulders and cobbles mixed with apparent silty sand, gray

Note that the description of soil conditions described above represents a summary of conditions as indicated in the provided materials and is included only to assist in evaluation of the load test data. For details regarding the soil conditions at the test site and elsewhere, the reader may reference the project Geotechnical Reports completed by the Geotechnical Engineer of Record.

**FOUNDATION DESCRIPTION**

The shaft had a nominal diameter of 96 inches and an overall length of 115.0 feet (top of concrete Elevation +1065.0 feet and shaft tip Elevation at +950.0 feet). The shaft was cased from approximately +1067.5 feet to Elevation +1015.5 feet. The river water depth extended to Elevation +1039.0 where the ground surface was encountered.

The shaft was drilled using polymer slurry and concrete was placed with the pump-and-tremie method. Shaft caving was encountered in the lower 10 feet of the shaft. To complete the shaft unreinforced concrete was placed in the bottom approximately 30 feet of the shaft and allowed to set. The concrete was then excavated to Elevation +950.0 feet. A dimensional analysis of the shaft was performed before the concrete plug was placed and after the concrete plug was excavated using a caliper. The results of the dimensional analysis are included in Appendix B. A reinforcing cage consisting of thirty #14 vertical bars with #6 bar hoops was then placed in the excavated shaft. AFT personnel in conjunction with Veit installed a single level jack assembly consisting of three AFT-Cells, telltale casings, displacement sensors, and five levels of four sister bar strain gages onto the reinforcing cage. As-built shaft instrumentation drawings and construction records are included in Appendix B. Construction was completed on October 27, 2018.

AFT was not under contract to document the shaft installation but have provided this summary based on our observations and understanding of the construction information.

**TEST SETUP AND INSTRUMENTATION**

The bi-directional static load test method loads the shaft in two directions by hydraulically pressurizing an embedded jack (AFT-Cell) assembly within the shaft. Pressurizing the jack assembly simultaneously loads the shaft below the AFT-Cell assembly that resists downward movement and loads the shaft above, which resists upward movement. The load is determined by relating the applied hydraulic pressure to the jack calibration. The jack assembly for this test shaft consisted of three AFT-Cells at a single level. Supplementary instrumentation was also installed in the test shaft to obtain detailed data on load transfer as described in the following sections. A description of the instrumentation used during the test is given below. Calibration data is provided in Appendix C. Various key dates related to the testing sequence are summarized in Table 2.





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Final Data Report of Bi-Directional Static Load Testing  
Rainy River Bridge - Baudette, Minnesota

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**Table 2. Load Testing Key Dates Summary**

Foundation Designation	Date Shaft Constructed	Load Test Date
Test Shaft	October 27, 2018	November 8, 2018

- AFT-Cell – The AFT-Cell is manufactured by Applied Foundation Testing in the USA. The load is determined using the jack calibration attached in Appendix C to relate applied load and hydraulic pressure. Both a calibrated digital pressure gauge and electronic pressure transducer monitor the applied pressure during testing. The pressure transducer was used for analysis and the digital gauge was used for visual reference and redundancy for the transducer.
- Expansion of AFT-Cell assembly – at the cell level is measured directly by four embedded LVWDTs attached to the jack assembly and spaced at 90 degrees. The LVWDT armature was fixed to the top bearing plate and the LVWDT body was rigidly fixed to the bottom bearing plate. The LVWDTs have a travel distance of 9 inches and were read to a 0.005-inch precision.
- Shaft Elastic Compression – Elastic Compression was measured using two (2) telltale assemblies, spaced at 180 degrees, consisting of a ½ inch pipe casing with an inner ¼ inch steel rod, extended from the top of the jack assembly. The telltale assemblies were monitored by LVDTs attached to the top of shaft. The indicators have a travel of 2 inches and are read to a 0.0001-inch precision. The stems of the indicators are aligned parallel and fixed to the telltale rod.
- Upward Top of Shaft Movement – was measured using two automated digital survey levels (Leica, Model DNA 03). The survey levels were supported by a stable platform the river. All survey levels monitored an INVAR barcode staff rigidly mounted to the top of shaft. The survey-level / INVAR rod reference system has a 0.001-inch precision.
- Strain Gages – were installed on five levels consisting of four “sister bar” type instruments manufactured by Applied Foundation Testing (Micro-Measurements gage type CEA-06-125UW-350). The lead cabling was a multi-conductor with shielded wires with a highly robust extrusion molded casing. The gages are installed at the levels shown in the drawings in Appendix A. The gages on each level were spaced at 90 degrees. The sister bar gages have an accuracy of 1.0 µε.
- Data Acquisition System – a National Instruments CompactDAQ™ was used to monitor the instrumentation. A laptop computer controlled the data acquisition system. Instrumentation readings were taken at 5-second intervals during the test. The system provides two levels of backup for all recorded data. In addition, manual records were maintained during the test as an additional backup.



## TEST PROCEDURES

Testing began by pressuring the AFT-Cells to break the tack welds at their base that hold them closed for handling and form a fracture plane in the drilled shaft. The fracture load occurred at 1587 kips. Note that all instrumentation was zeroed prior to this initial load-unload cycle.

The bi-directional static load test was conducted following load increments specified in the submittal document. This consisted of one load cycle with 20 increments of 400 kips (5% of 8,000 kips) targeted for approximate eight-minute holds. During the 18<sup>th</sup> increment all five hydraulic pumps became frozen and were damaged by the extreme weather conditions. The load was then allowed to drop to zero in five decrements of 1,476 kips (20% of 7,382 kips) using approximately four-minute holds. Measured loads and displacements are displayed in Figures 1 and 2.

## TEST RESULTS AND ANALYSIS

General: The loads applied by the embedded jack act simultaneously on the shaft above and below its location. The load acting upward is assumed to be zero until the weight of the shaft above is overcome; this is consistent with current industry analysis practice. The *net load* is therefore the *gross load* minus the weight of the shaft above the load cell assembly. The calculated buoyant weight for the test shaft was approximately 454 kips.

Load and displacement is presented in Figure 1. Load versus time and displacement versus time plots are given in Figures 2 and 3.

Load transfer during testing was determined using the embedded strain gage measurements shown in Figure 4. The calculated load at each gage level is shown in Figure 5. Load distribution versus elevation is given in Figure 6.

The test shaft geometry described earlier in this report was used in the calculation of load from the measured strains. The measured strains at each strain gage level were averaged to calculate the strain in the shaft cross section. Load at each gage level shown in the figures was calculated by multiplying the average strain by the respective cross-sectional area and composite modulus of elasticity (stiffness).

The composite shaft modulus is determined by weighting the individual modulus of the steel and concrete by their respective cross-sectional areas. In this way, the concrete modulus is calculated using the ACI 363 formula:  $E_c = 40,000\sqrt{f'_c} + 1,000,000 \text{ psi}$  with the closest average concrete strength at the time of testing. Concrete compressive strength testing indicated an average  $f'_c$  of 2,500 psi and 4,200 psi on November 6 and November 7, respectively. Concrete compressive strength testing on November 6 was performed on a field cured cylinder, while testing done on November 7 was performed on a lab cured cylinder. An assumed in place average  $f'_c$  of 2,940 psi was used in the strain gage analysis. This value corresponds to 70% of the concrete compressive strength observed on November 7. This reduction agrees with data observed during the load test and is typical in the experience of AFT.



Unit side shear values were then determined by subtracting the calculated loads at each strain gage level and dividing by the respective segment surface area. The shaft diameters used in the analysis are based on the average shaft diameters over the segment length as shown in Report of Dimensional Analysis, dated October 31, 2018. Segmental unit side shear values are presented in the form of a t-z curve or soil response curve. In the t-z curve, the displacement shown is at the midpoint of the segment.

Upper Side Shear: The upper side shear above the cell level was not fully mobilized during the test and experienced a maximum load and displacement of 0.22 inches at 7,382 kips. Correcting for buoyant weight, the applied load was 6,928 kips. The upper t-z curves are presented in [Figure 7](#). Calculated values for the maximum unit side shear values observed during the test are provided in [Table 3](#). As shown in the graphs and the table above, the side shear values in segments 5 and 6 appear low in comparison to segment 4. Given the soil profile at the test site, these low values are anomalous. In our opinion, the use of the concrete plug during shaft construction impacted the load transfer in the plug zone.

Tip Resistance: The unit side shear for the shaft segment extending from the base of the cell assembly to the shaft tip has been subtracted from the applied load used to calculate tip resistance. Because there were no strain gages located below the cell assembly, we assumed that the unit side shear in this zone is the same as the unit side shear in the segment immediately above the cell assembly. This is consistent with standard industry practice. The q-z plot is presented in [Figure 8](#).

Equivalent Top Load versus Displacement: An equivalent top load versus displacement curve is presented in [Figure 9](#) based on the load and displacement data. Also shown on this figure is the displacement corrected for elastic shortening that would occur if the shaft was loaded from the top. The theoretical elastic shortening was calculated using the t-z values obtained during testing. The incremental compression was then estimated at each segment. Equivalent top load was computed using a finite element calculation of load shed and elastic compression for each segment of the shaft. For a top loading of 8,412 kips, the elastically corrected data projects the shaft would have experienced 0.54 inches of displacement using a third order polynomial fit of the rigid body behavior.

Creep Limit: Data in [Figure 10](#) indicates the creep observed during the test. Because of the minimal amount of creep observed it is our opinion that the creep limit was not observed during the test.

Final Data Report of Bi-Directional Static Load Testing  
Rainy River Bridge - Baudette, Minnesota**Table 3. Load Transfer Summary**

Location	Segment Top / Segment Bottom Elevation (feet)	Soil Type	Layer Displacement (inches)	Peak Unit Side Shear Resistance (ksf)
Segment 1	+1065.0 to +1012.1 (Casing from +1067.5 to +1015.5)	Poorly graded sand, coarse to fine grained, brown to gray, wet to water bearing, very loose and lean clay with a trace of gravel, little to some sand, gray, wet, medium to soft	0.13 ↑	0.30 ↑
Segment 2	+1012.1 to +1002.1	Silty sand with a trace to a little gravel and a trace of clay, gray, moist to wet, slightly plastic, very dense	0.13 ↑	5.61 <sup>1</sup> ↑
Segment 3	+1002.1 to +992.1	Boulders and cobbles mixed with apparent silty sand, gray	0.14 ↑	3.59 <sup>1</sup> ↑
Segment 4	+992.1 to +982.1 (End of Concrete Plug at +984.5)	Boulders and cobbles mixed with apparent silty sand, gray	0.15 ↑	12.86 <sup>1</sup> ↑
Segment 5	+982.1 to +972.1 (Inside Concrete Plug)	Boulders and cobbles mixed with apparent silty sand, gray	0.17 ↑	3.07 ↑
Segment 6	+972.1 to +963.1 (Inside Concrete Plug)	Boulders and cobbles mixed with apparent silty sand, gray	0.20 ↑	2.69 ↑
<b>AFT-Cell™ Assembly +963.1 to +961.6</b>				
Toe Segment	+961.6 to +950.0 (Inside Concrete Plug)	Boulders and cobbles mixed with apparent silty sand, gray	2.77 ↓	2.69 <sup>2</sup> ↓
<b>End Bearing</b>			<b>2.77 ↓</b>	<b>133.09<sup>1</sup> ↓</b>

1. Not fully mobilized.

2. Assumed for end bearing calculation purposes.



## **CLOSURE**

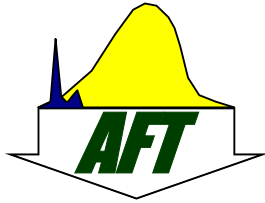
We want to thank you for the opportunity to be involved in this project. Please do not hesitate to call us if you have any questions regarding the information in this report.

## **LIMITATIONS**

This report presents test measurements made by AFT. Interpretations were made based upon the measurements made by AFT with the latest techniques available and currently accepted standards of care recognized by Geotechnical Engineering professionals. AFT is an independent agency and is not the Geotechnical Engineer of Record. The Geotechnical Engineer of Record should ultimately make final recommendations for foundation design and construction.

## **REFERENCES**

Housel, William S. "Dynamic and Static Resistance of Cohesive Soil." ASTM International. *Papers on Soils, 1959 Meetings*. PP 4-33.



## **Appendix A**

### **Load Test Result Figures**

#### **Report of Bi-Directional Load Testing – Test Shaft**

Rainy River Bridge  
Baudette, Minnesota

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AFT-Cell Gross Load vs Displacement  
Rainy River Bridge  
Test Pile

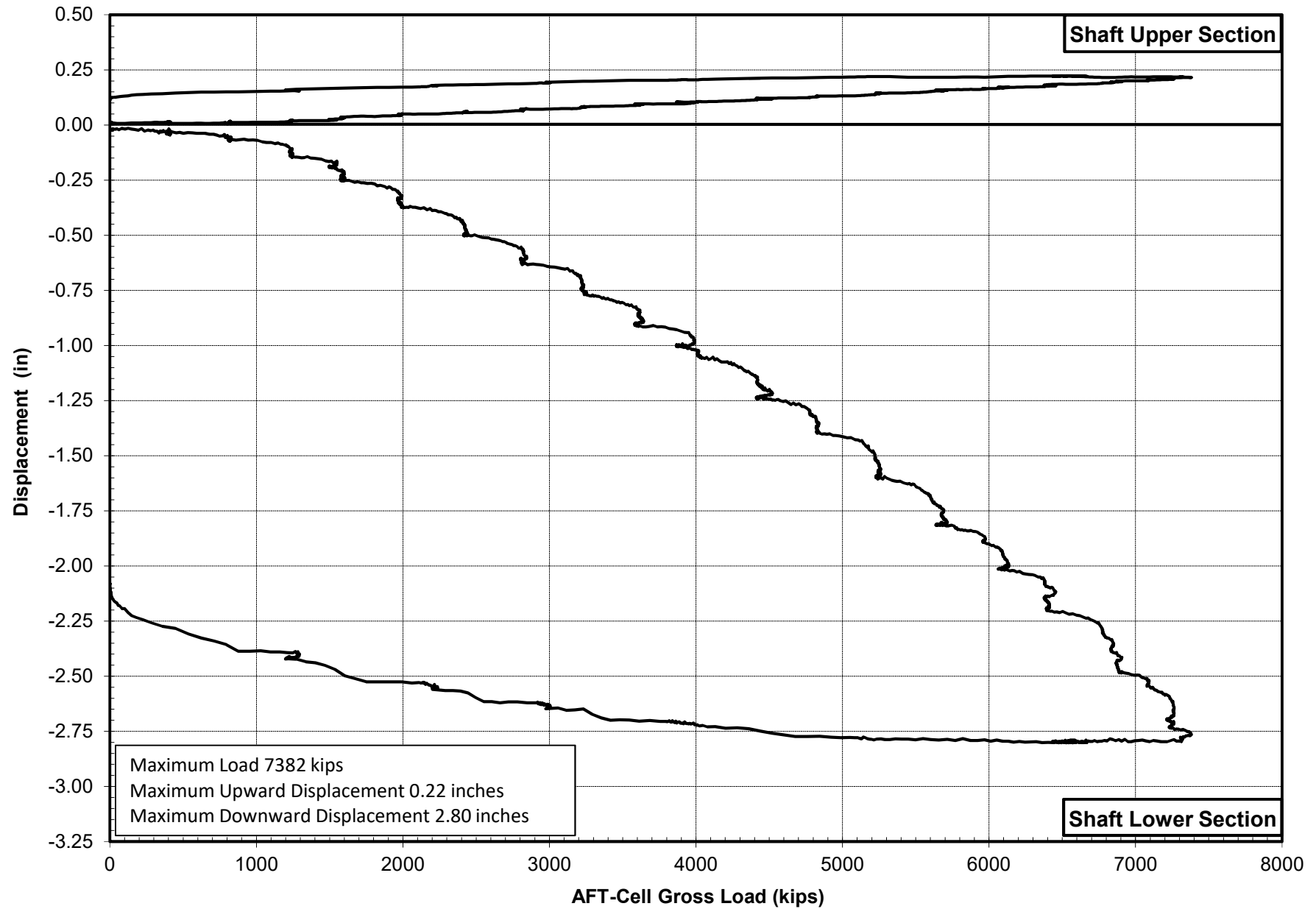


Figure 1



AFT-Cell Load vs Time  
Rainy River Bridge  
Test Pile

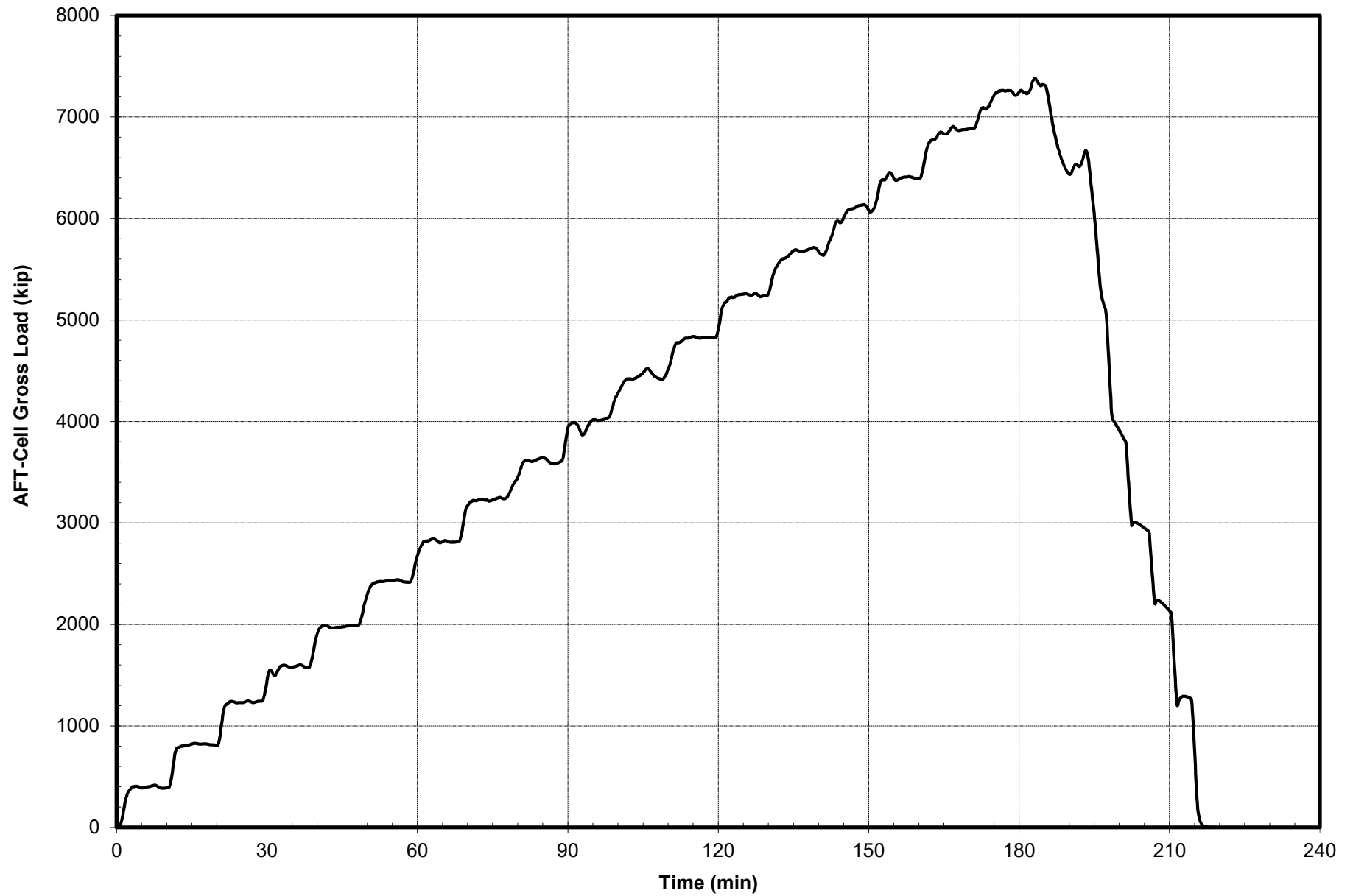


Figure 2



AFT-Cell Displacement vs Time  
Rainy River Bridge  
Test Pile

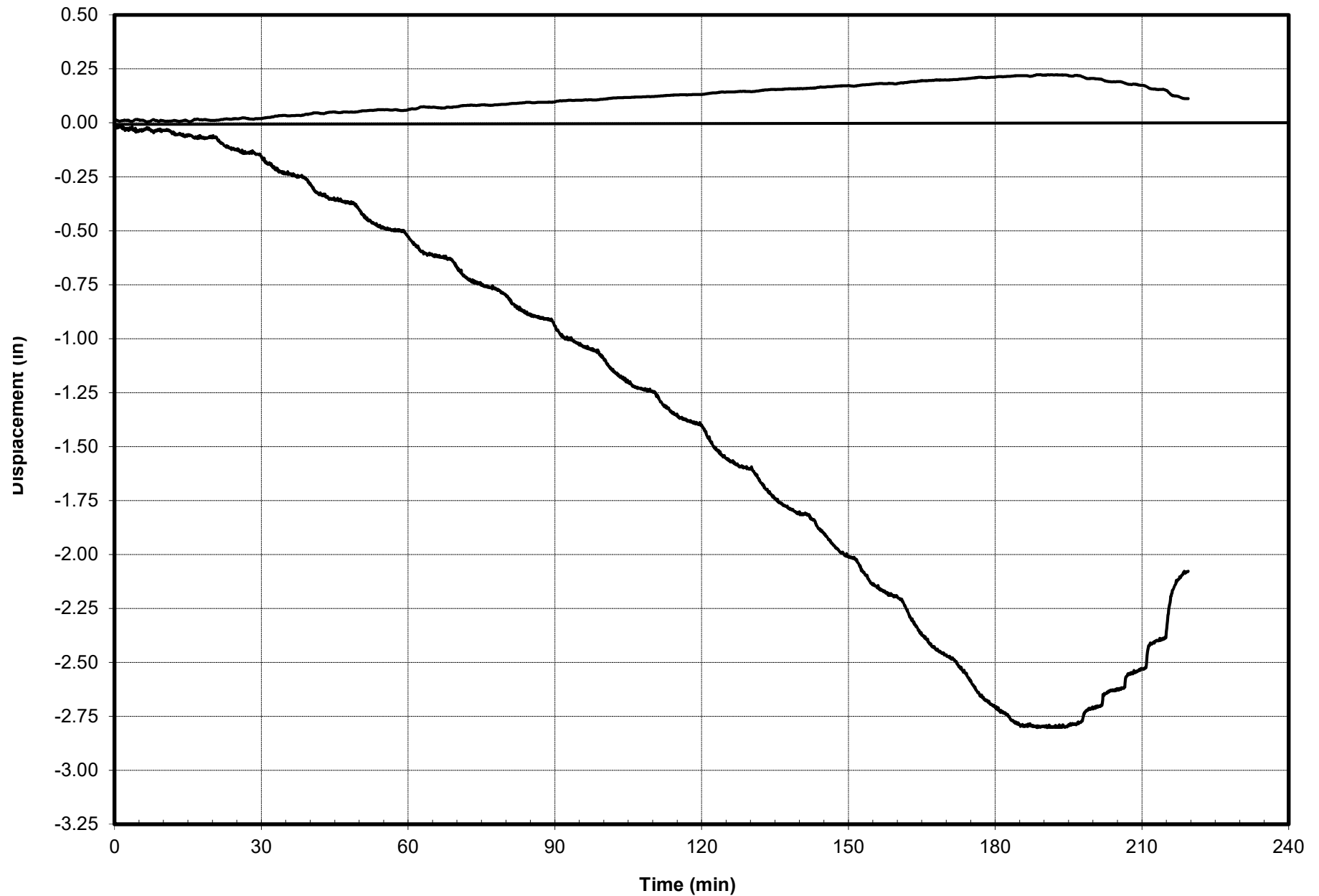


Figure 3

Upper Section Strain vs Time  
Rainy River Bridge  
Test Pile

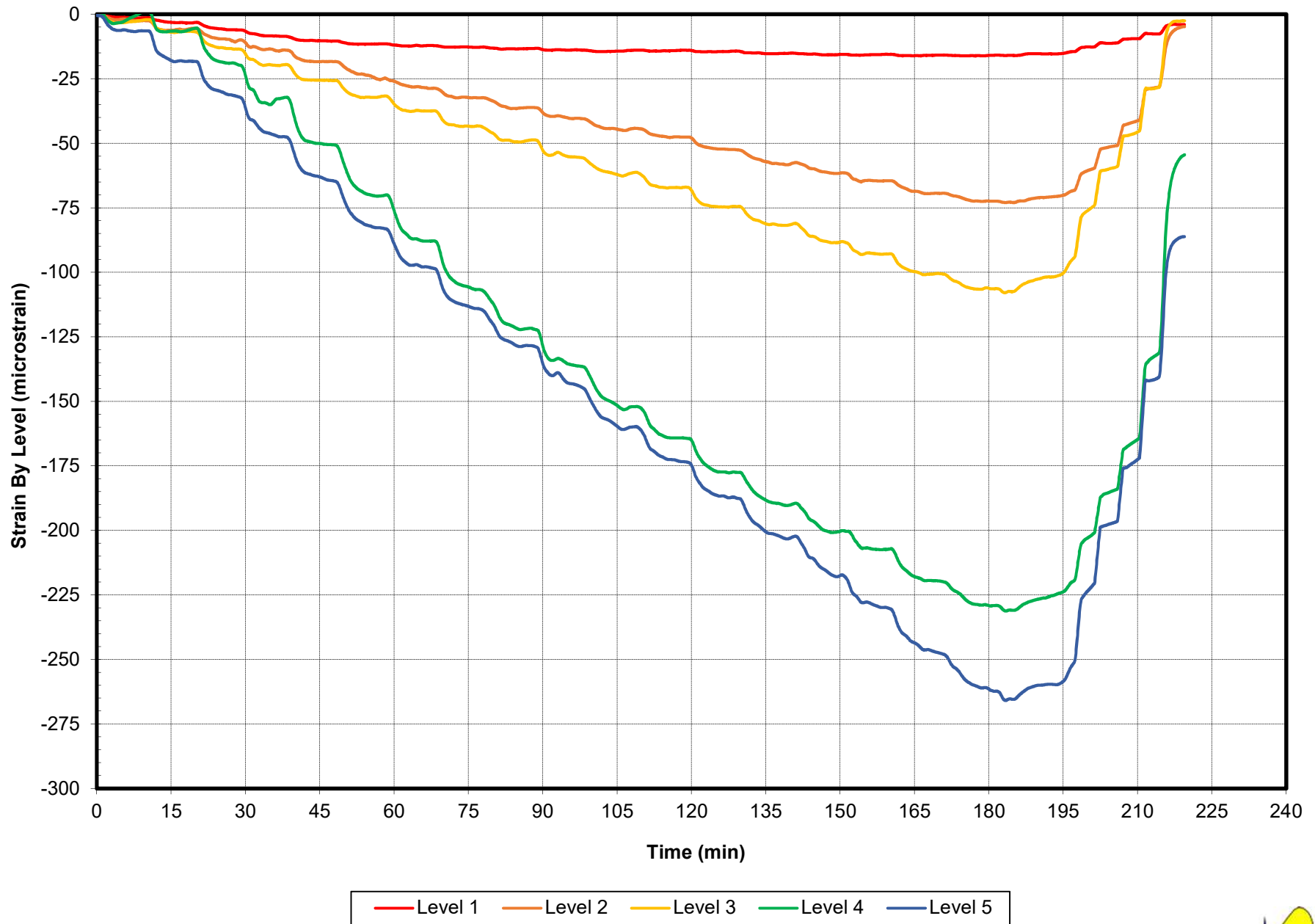


Figure 4

Upper Load Distribution vs Time  
Rainy River Bridge  
Test Pile

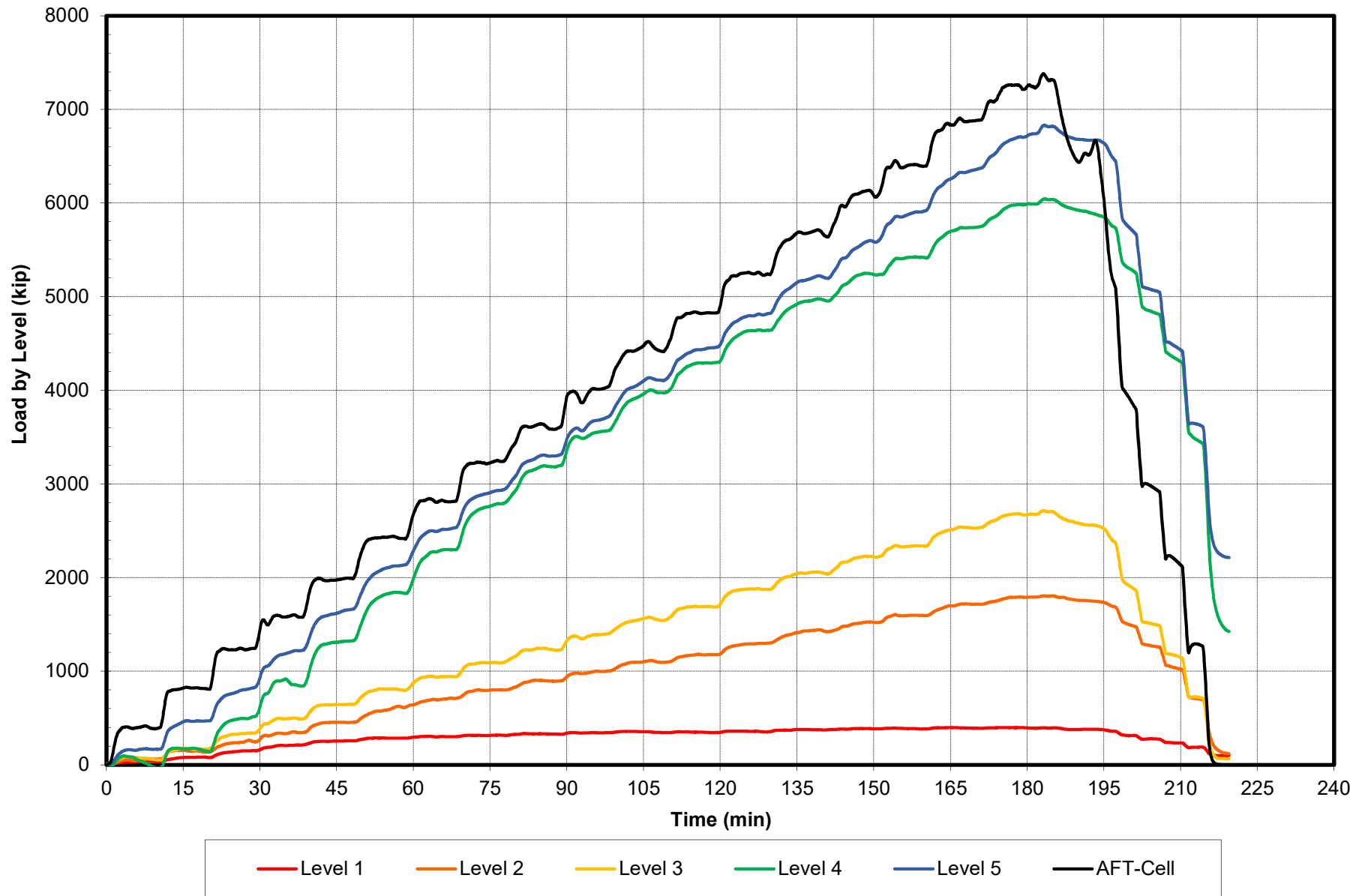


Figure 5



# Elevation Load Distribution Rainy River Bridge Test Pile

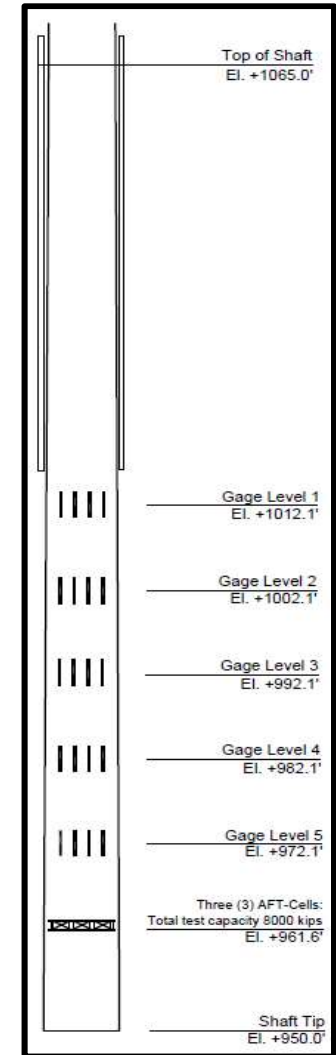
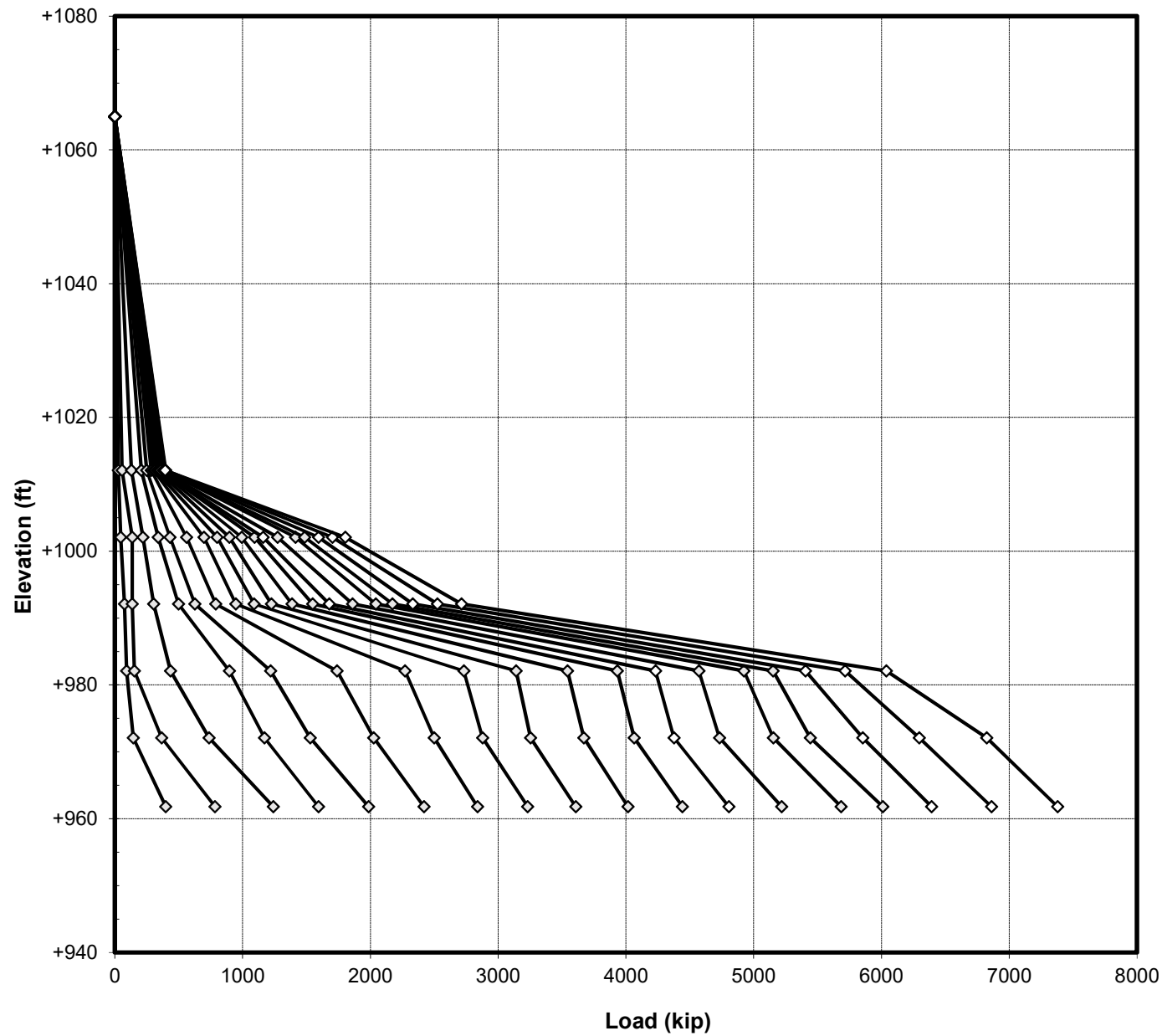


Figure 6

Upper Section Unit Side Shear ( $\tau_z$ )  
Rainy River Bridge  
Test Pile

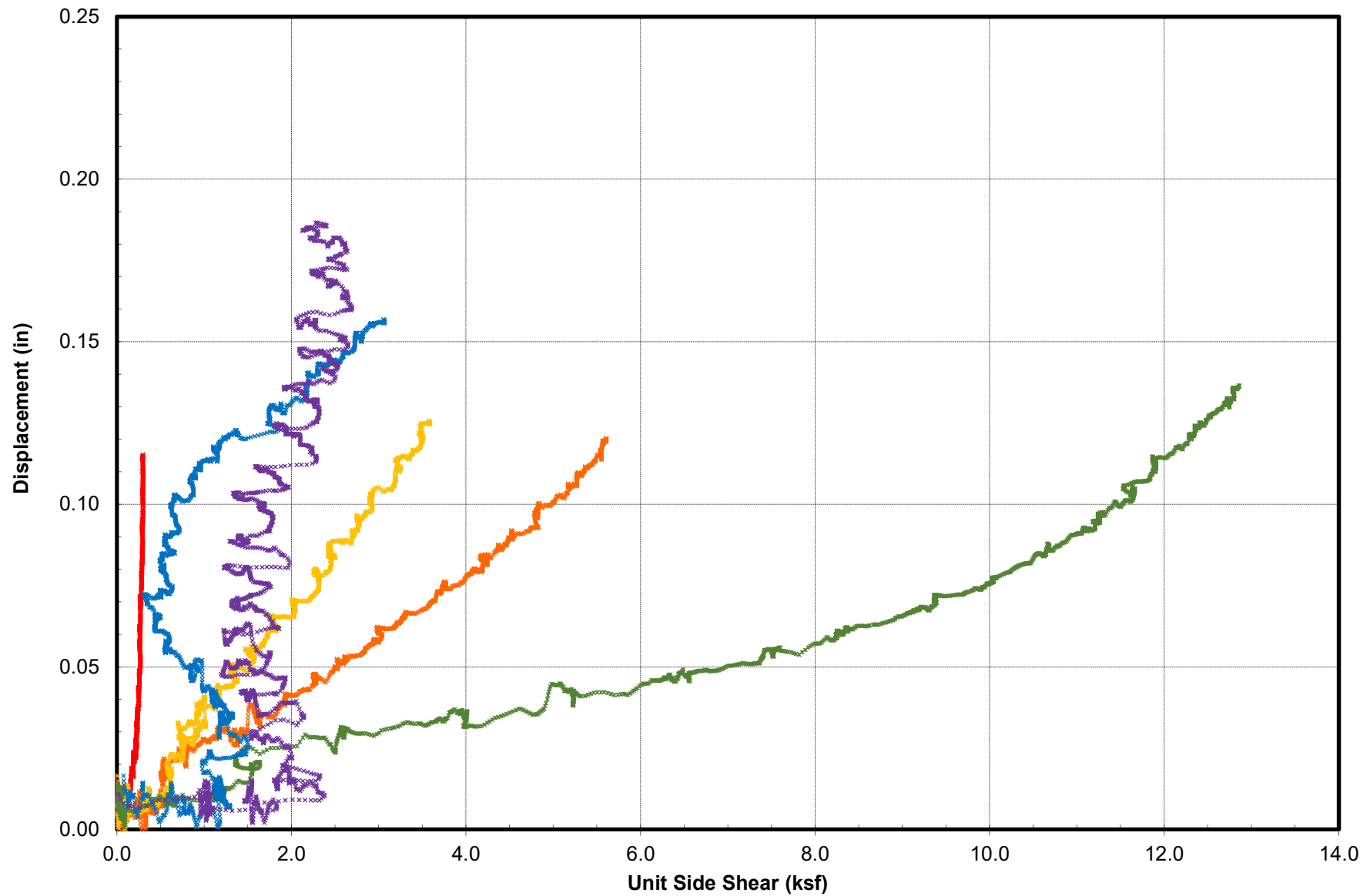


Figure 7

End Segment Resistance  
Rainy River Bridge  
Test Pile

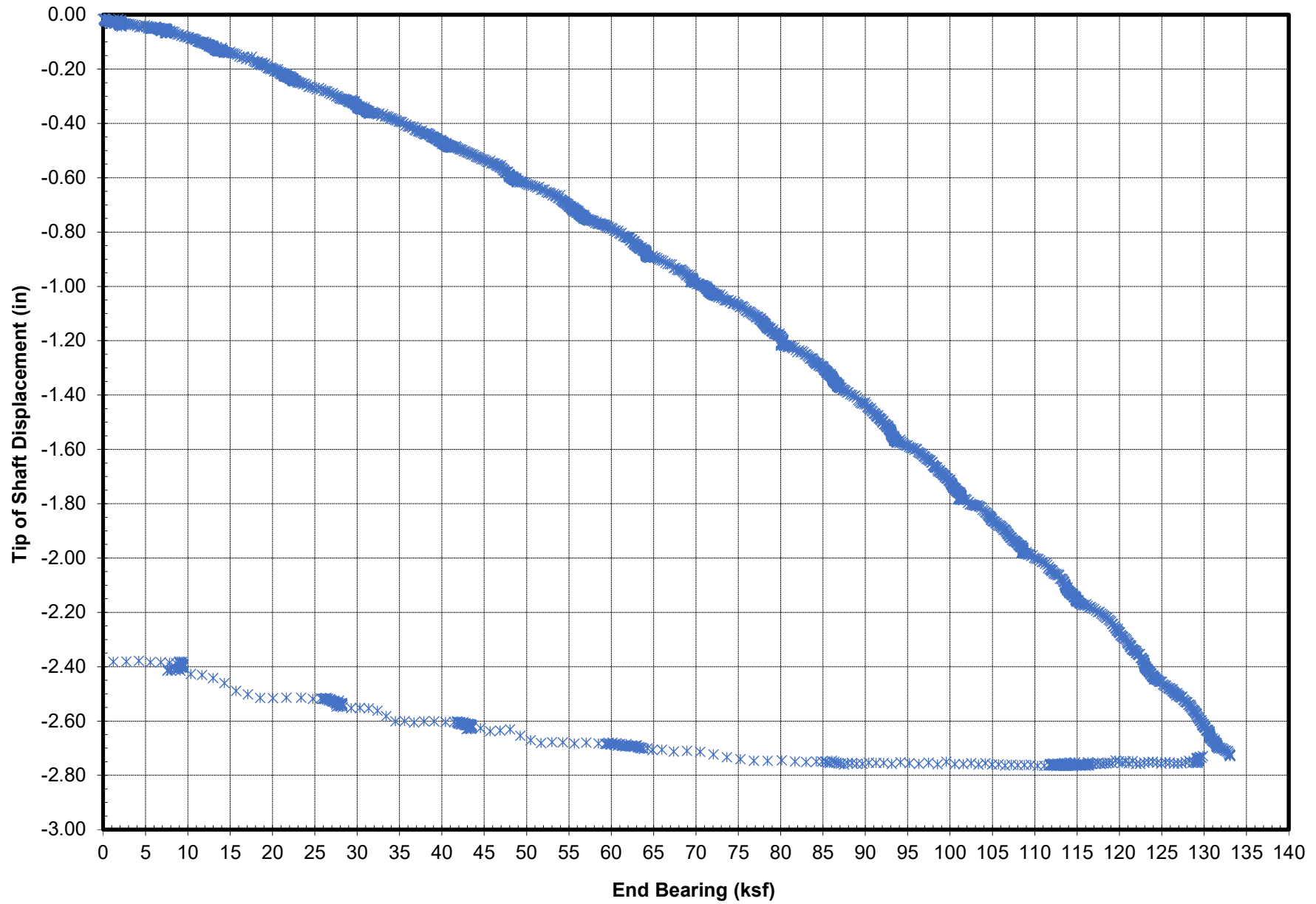


Figure 8

### Equivalent Shaft Top Load vs Displacement Rainy River Bridge

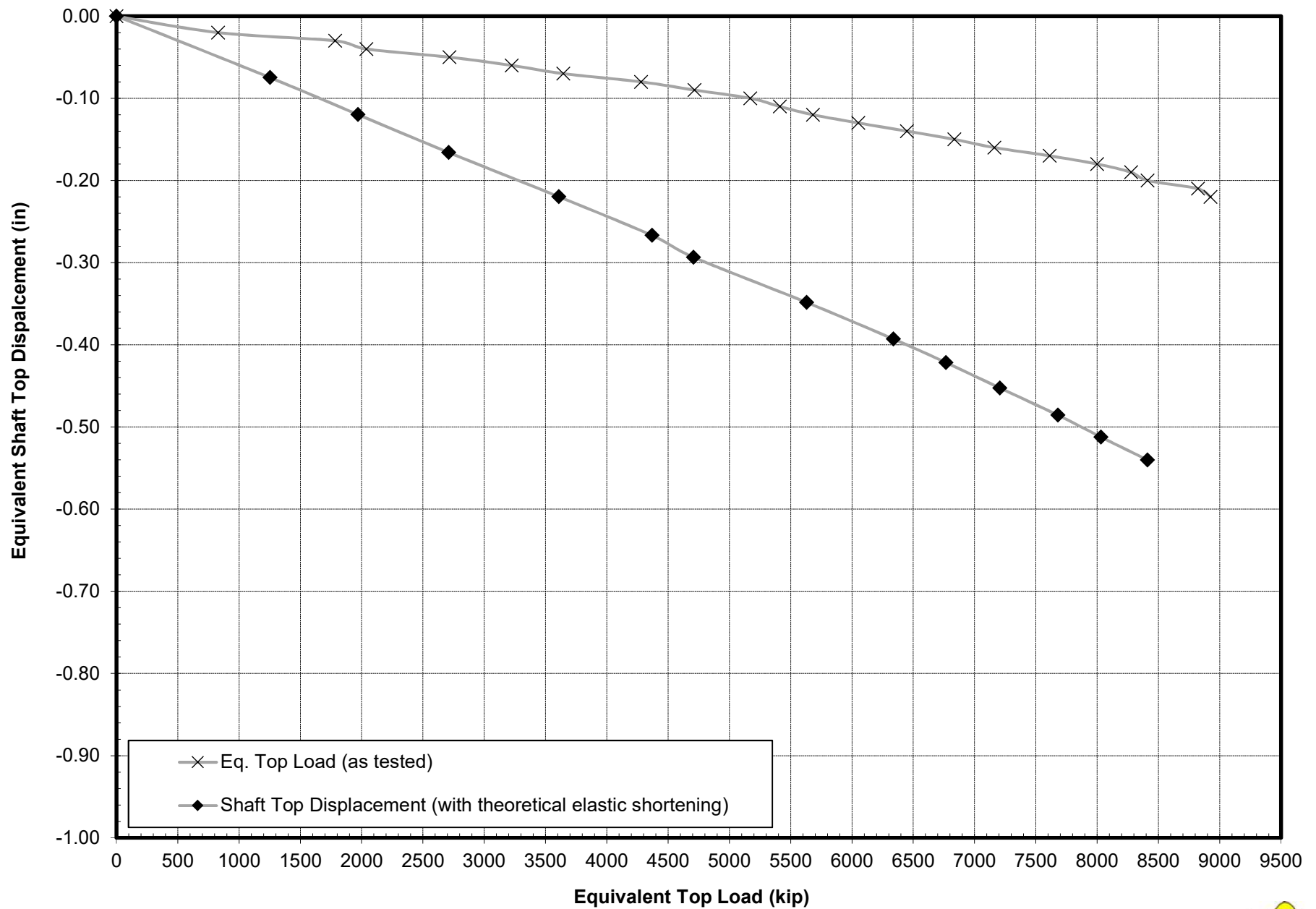


Figure 9

Creep Limit - Composite of All Stages  
Rainy River Bridge  
Test Pile

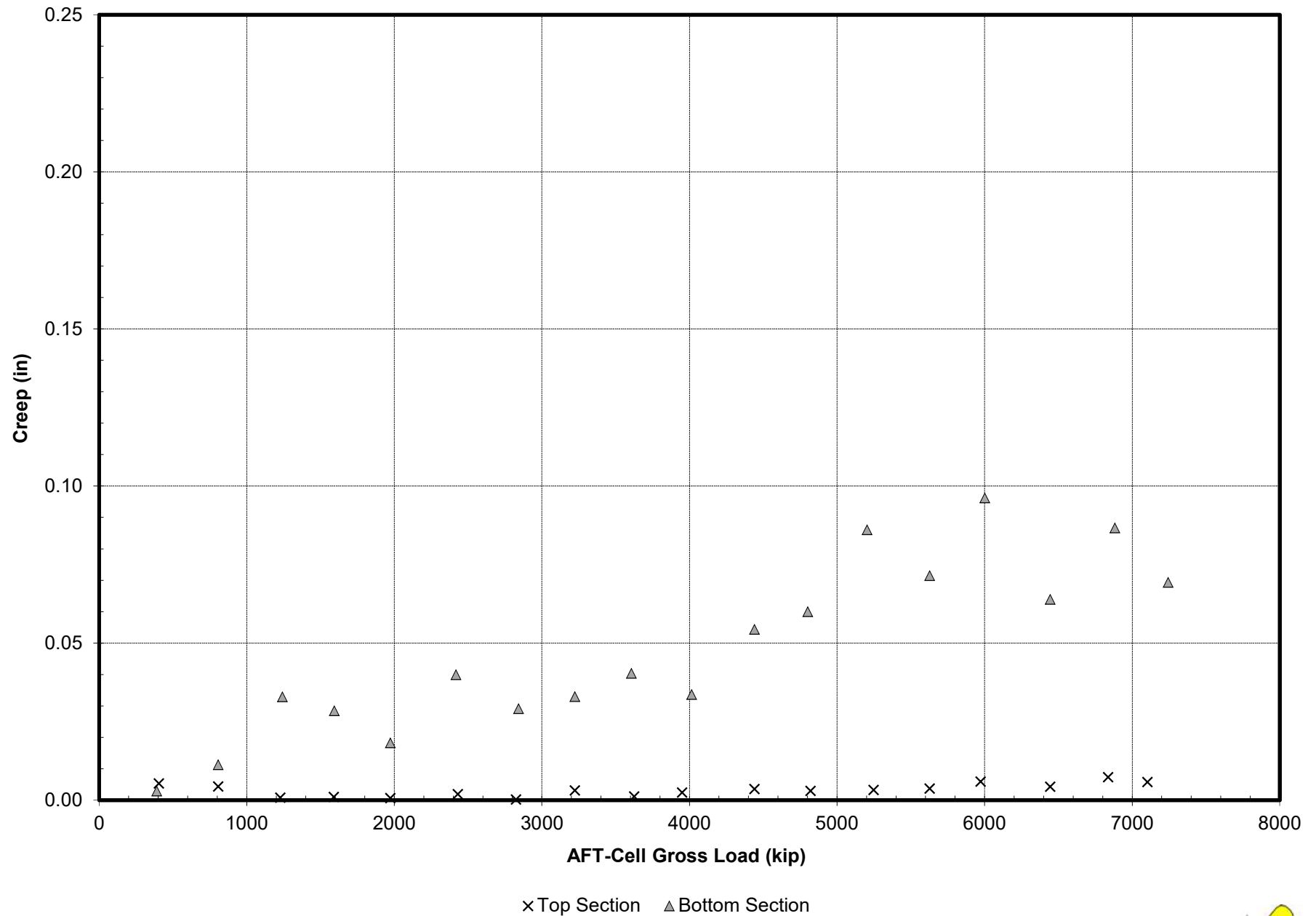
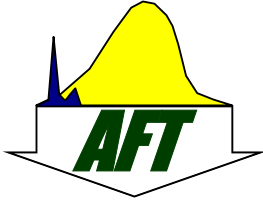


Figure 10







**Appendix B**  
**As-Built Schematic Drawing**  
**Shaft Construction Records**  
**Input/Analysis Parameters**  
**Boring**

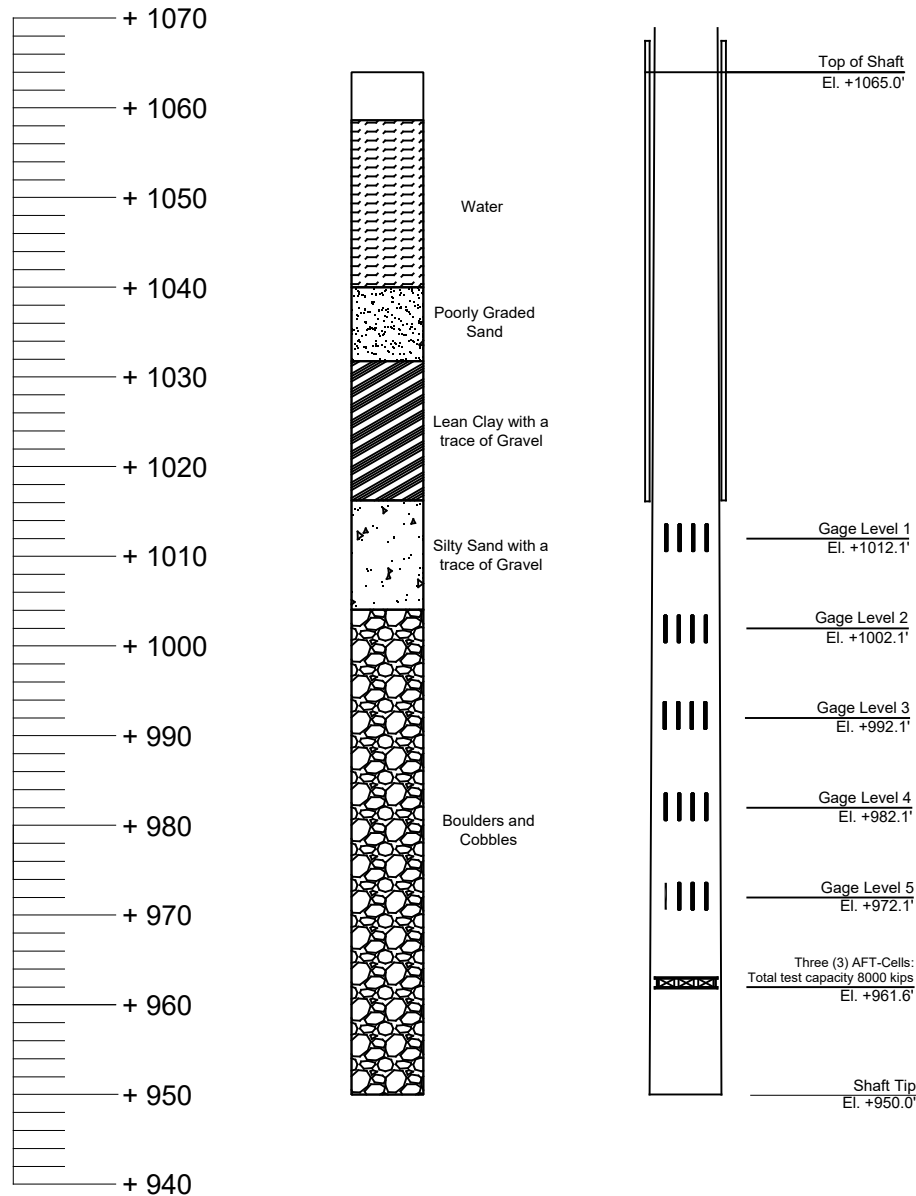
**Report of Bi-Directional Load Testing – Test Shaft**

Rainy River Bridge  
Baudette, Minnesota

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# AFT-Cell Test Schematic

Ø96" x 111.5' Test Shaft  
Rainy River Bridge



Applied Foundation Testing, Inc.  
4035 J. Loius Street  
Green Cove Springs  
Florida, 32043

Title: AFT-CELL TEST SCHEMATIC ELEVATION VIEW

Project: Rainey River Bridge

AFT Project #: 518053

Author: MC/AB

08/15/2018

Figure: 1

## SUMMARY OF DIMENSIONS, ELEVATIONS AND SHAFT PROPERTIES

### Job Information:

Shaft Number:	Test Pile
Project Name:	Rainy River Bridge
Project Number:	518053
Project Location:	Baudette, MN

### Shaft:

Nominal Shaft Diameter	=	96 in.
Elevation of top of shaft concrete	=	+1065 ft.
Elevation of shaft base	=	+950 ft.
Shaft Base Area	=	50.26 ft. <sup>2</sup>

### Cell Level:

Elevation of base of AFT-Cell assembly	=	+961.8 ft.
Length of Shaft above base of AFT-Cell	=	103.2 ft.
Length of Shaft below base of AFT-Cell	=	11.8 ft.
Nominal side shear area above AFT-Cell base	=	2593.69 ft. <sup>2</sup>
Nominal side shear area below AFT-Cell base	=	296.56 ft. <sup>2</sup>

### AFT-Cell:

AFT-Cell Diameter	=	24 in.
AFT-Cell Serial Number	=	068, 071, 092
AFT Cell bottom plate diameter	=	74 in.
AFT Cell top plate diameter	=	74 in.
AFT Cell bottom plate thickness	=	2 in.
AFT Cell top plate thickness	=	2 in.

### Telltales:

Compression telltale top elevation	=	+1070 ft.
Compression telltale bottom elevation	=	+963.1 ft.

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**SUMMARY OF DIMENSIONS, ELEVATIONS AND SHAFT PROPERTIES**

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**Strain Gages:**

Elevation of Strain Gage Level 1 (Red)	=	+1012.1 ft.
Elevation of Strain Gage Level 2 (Orange)	=	+1002.1 ft.
Elevation of Strain Gage Level 3 (Yellow)	=	+992.1 ft.
Elevation of Strain Gage Level 4 (Green)	=	+982.1 ft.
Elevation of Strain Gage Level 5 (Blue)	=	+972.1 ft.

**Steel Properties:**

Reinforcing cage vertical bar size	=	#14
Number of vertical bars	=	30
Reinforcing cage diameter	=	79 in. <sup>2</sup>
Reinforcing cage spiral size	=	#6
Area of Steel	=	67.5 in. <sup>2</sup>

**Concrete Properties:**

Assumed concrete unit weight	=	150 lb/ft <sup>3</sup>
Reported unconfined compressive concrete strength	=	2940 psi

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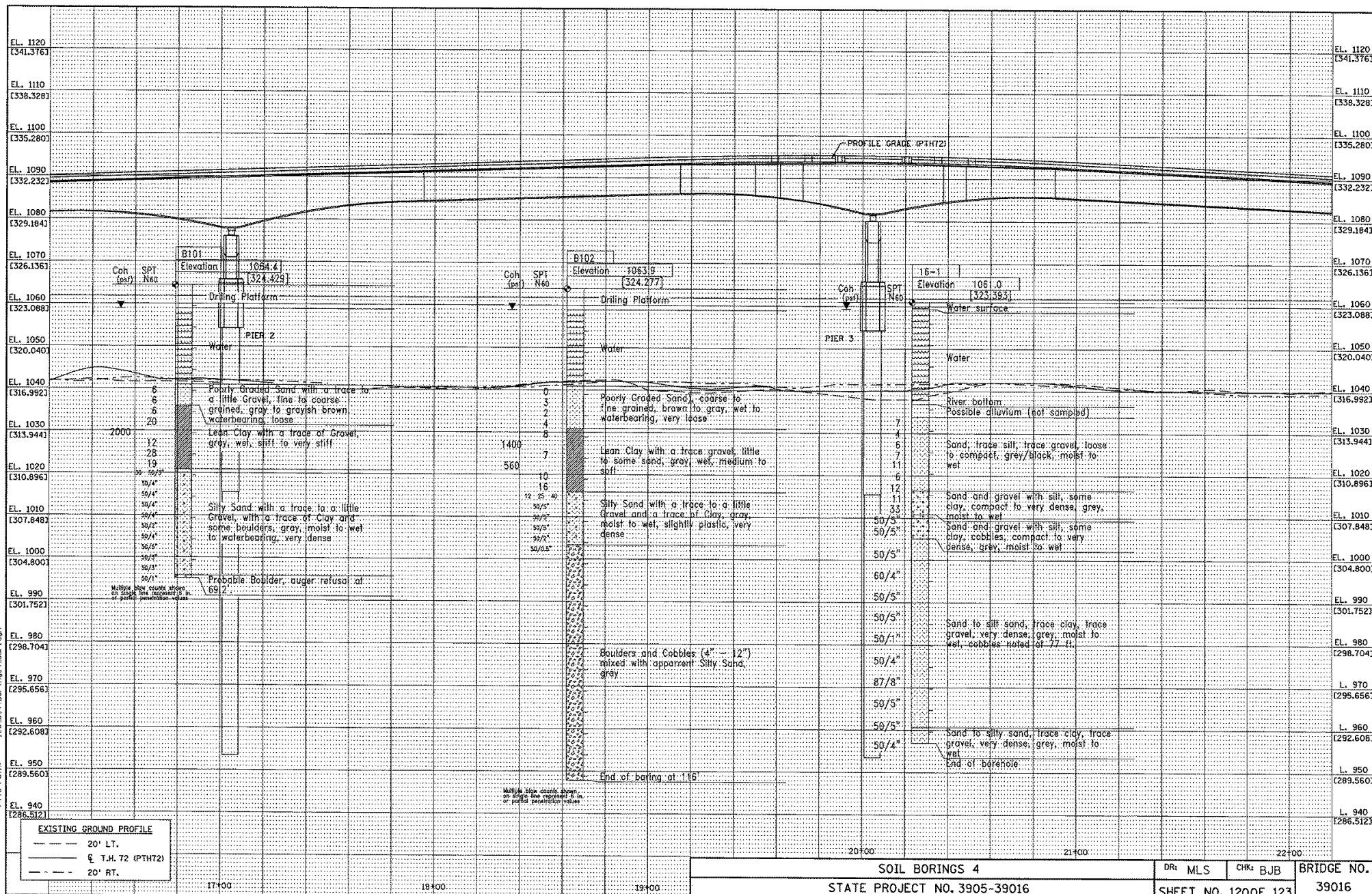
**SUMMARY OF DIMENSIONS, ELEVATIONS AND SHAFT PROPERTIES**

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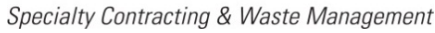
**Shaft Segment Definitions:**

Segment	Top Elevation (ft)	Bott Elevation (ft)	Diameter (in)	Buoyant Weight (kip)	Stiffness (kip)
1	1065.0	1012.1	96.0	232.93	24689601
2	1012.1	1002.1	96.0	44.03	24725792
3	1002.1	992.1	97.0	44.95	25169697
4	992.1	982.1	99.0	46.83	26141346
5	982.1	972.1	98.0	45.89	25691335
6	972.1	963.1	98.0	41.30	25653620
CELL	963.1	961.6	96.0	0.00	24653410
TIP	961.6	950.0	96.0	0.00	24689601

00010292  
 Date Plotted: 13-Nov-2017  
 Time Plotted: 2:00:50 PM  
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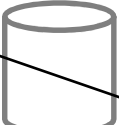



APP. 18-4-17



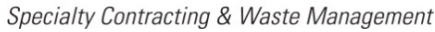
<b>Project Name:</b>	Baudette Bridge			
<b>Veit Project #:</b>	180153		<b>Pier No.</b>	Technique Shaft
<b>Client:</b>	MNDOT		<b>Area:</b>	
<b>Driller:</b>	Sam hendrickson	<b>Date</b>	<b>Grid Line:</b>	
<b>Inspected By:</b>	MNDOT/DBA	<b>Date</b>		

[illegible]

Alignment	Vertical	Reinforcing Steel	Ordered (cy)	240
		# Verts: _____	<b>Legend</b> (Indicate on graphic drilled shaft)	
		#Hoops: _____		
		Dowels: Yes / No	 1060	Water Table
			TOC 1067	Top of Casing
			TOG 1039	Top of Ground
			TOS 1065	Top of Shaft
			TOR 1015	Top of Socket
			BOC 1015	Bottom of Casing
			BOS 950	Bottom of Shaft
Tolerance: _____	Tolerance: _____			

All rebar by Lunda/Harris Rebar

Comments/Notes:  
(Flow Volume, Hydrostatic head, elevation encountered)  
Top of rebar-1064  
Bottom of rebar-960.5 (8' cut off from bottom)bottom of rebar cage cut off due to damage incurred during installation in the shaft - directed by David Graham of Dan Brown & Assoc (geotechnical engineer)  
\*\*socket diameter varies due to boulder obstruction removal



## Page 2 of 2

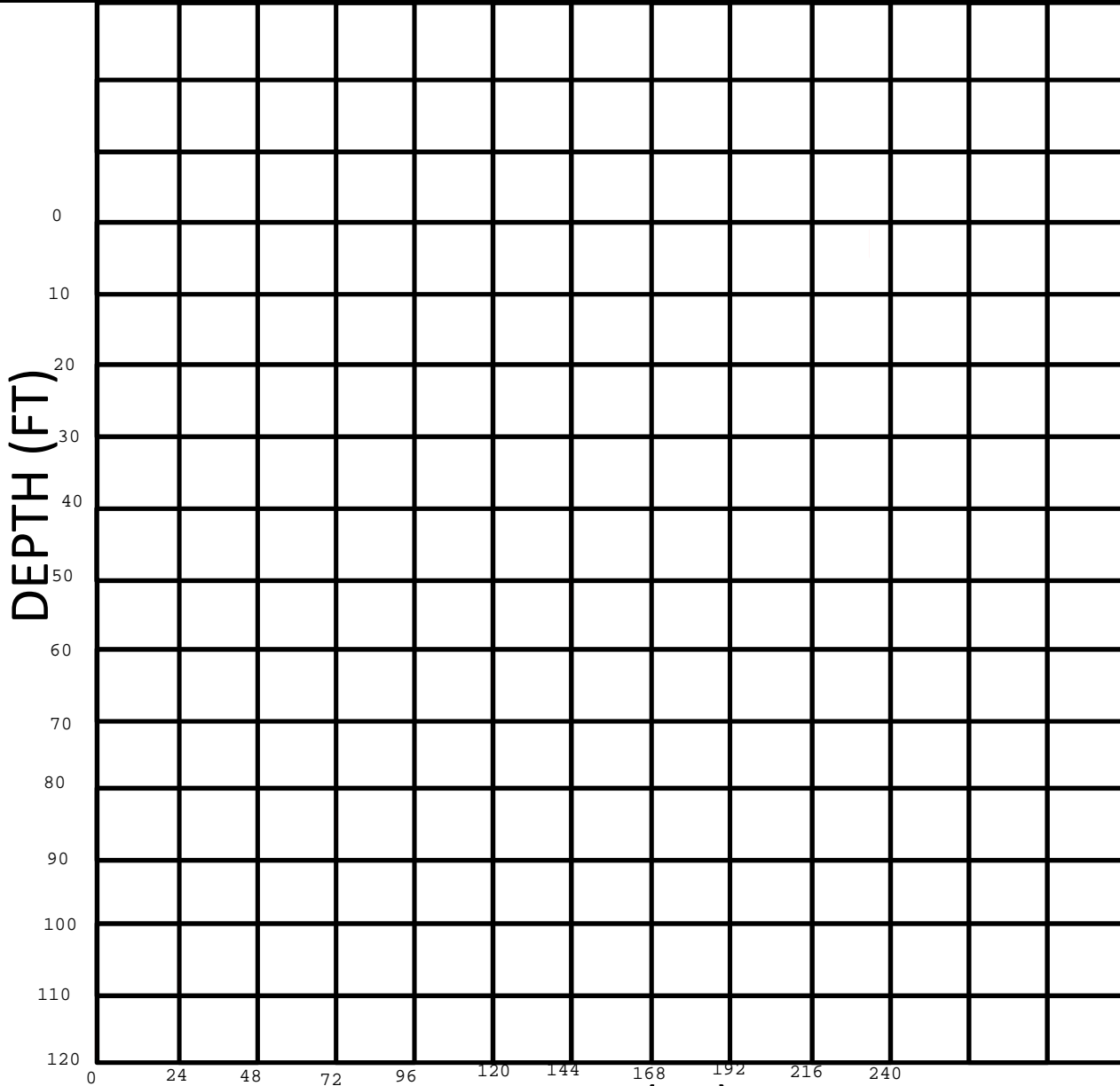
Date Revised: 4-23-15



Specialty Contracting & Waste Management

# Concrete Placement Curve

Project Name:	Baudette Bridge	Page 3 of 3	
Project #:	180153	Pier No.	Technique Shaft
Client:	MNDOT	Shaft No.	
Drill Foreman:	Jean Guy Trepanier	Date	
Placement Method		Column / Row	
		Mix Number:	



Concrete(CY)

240 Volume Delivered (cy)  
VD

Volume in Lines (cy)  
VL

Waste (cy)  
VW

230 Volume Placed (cy)  
VP = VD-VL-VW

201 Theoretical Volume (cy)  
VT

Overpour (cy)  
VP - VT

Cross Sectional Area (in<sup>2</sup>)  
AR = #bars / As

65.5 Soil Socket Length (ft)  
RSL

107 Est. Soil Socket Volume (cy)  
VRS

142 Actual Soil Socket Volume (cy)  
VRS\* = (AR)(RSL)/(3888) - VL

90\* Average Soil Socket Diameter (in)  
RSD = SQRT[(4950)VSL\*/RSL]



# MINNESOTA DEPARTMENT OF TRANSPORTATION

## DRILLED SHAFT REPORT

Bridge No. \_\_\_\_\_ S.P. No. 3509-09 Pier No. \_\_\_\_\_ Technique \_\_\_\_\_ Shaft No. \_\_\_\_\_  
Prime Contractor Lunda  
Drilled Shaft Contractor Veit MnDOT Inspector Ron Gjovik

### GENERAL INFORMATION

Date Shaft Construction Started 8/27/18  
Date Shaft Construction Completed 10/27/18  
River Pool Elev. 1059 Water Temp. 45 deg F  
Construction Method: Wet X Dry \_\_\_\_\_

### OBSTRUCTIONS

Description of Obstructions Encountered in Earth Shaft  
Rocks and boulders up to 4' in DIA removed

### Removal Methods and Tools Used

Various sizes of augers, core barrels, rock pickers, drilling buckets

### SHAFT INFORMATION

Permanent Casing Dia.: Plan 96 in  
As-built 96 in  
Date Permanent Casing Set 9/4/18  
Bottom Elev. of Permanent Casing 1015  
Top Elev. of Finished Shaft: Plan 1065  
As-built 1065  
Elev. of Initial Contact of Rock N/A  
Bottom Elev. of Drilled Shaft 950  
Rock Shaft Dia. Plan 90 in, As-built in 90\* Concrete Mix No. 3XJM  
Soil Socket

\*\*socket diameter varies due to boulder obstruction removal

### DRILLING INFORMATION

Drill Rig Make and Mdl. CZM EK250

Drilling Tools Used: \_\_\_\_\_

24-84" Auger with reamer,

24-90" core barrel, 90" drilling bucket

Excavation Tools Used: 94" cleanout bucket

96" Auger with reamer

Earth Drilling Start Date 8/27/18, Finish Date 10/25/18

Rock Drilling Start Date n/a, Finish Date n/a

Excavation Finished Date 10/25/18

Location and Extent of Rock Cavities or Shaft Caving:

large boulders located throughout the shaft every 1-5'

side wall boulders located at 70-74', 89-93' and 99-103'

uncased side walls caved in throughout shaft at  
time of first airlift, concrete plug poured to 984, redrilled

### ROCK SHAFT CLEANOUT PROCEDURE

Method n/a

Estimated Thickness of Sediment at Bottom of Shaft at Time  
of Concreting .7"

### CONCRETE PLACEMENT OBSERVATIONS

Placement Date 10/27/18

Ambient Temperature 40 deg F

Placement Method Pump Truck and Tremie

Total Placement Time 6.5 hours

Water Elev. in Shaft at Time of Conc. Placement 1065

### VARIATION OF SHAFT FROM PLUMB AND PLAN

#### LOCATIONS

Plumb n/a

Lateral n/a

### REMARKS/COMMENTS/NOTES

**MINNESOTA DEPARTMENT OF TRANSPORTATION**  
**DRILLED SHAFT CONSTRUCTION**

**Critical Activity Point Release Form and Checklist Prior to Concreting**

**Drilled Shaft Checklist:**

- ☒ Casing installed and free of damage?
- ☒ ~~Rock~~ socket drilled to minimum depth or greater?
- ☒ ~~Rock~~ socket cleaned out? Method of cleaning Cleanout bucket
- ☒ Mini-SID Inspection? Date/Time accepted 10/25/18
- ☒ Weighted Tape Inspection? Date/Time 10/25/18
- ☐ Other Inspection? Method \_\_\_\_\_
- ☐ Rebar materials certifications collected?
- ☐ Rebar cage correctly tied and coupled?
- ☐ CSL tubes properly installed (technique shaft)?
- ☒ TIP cables properly installed?
- ☒ Rebar cage installed into shaft? Date/Time 10/26/18

Remarks: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Required testing and inspection procedures have been performed and documented.

  X   YES           NO

**Signatures:**

Critical Activity Point Manager: \_\_\_\_\_ Date: \_\_\_\_\_

QCI (Foreman): \_\_\_\_\_ Date: \_\_\_\_\_

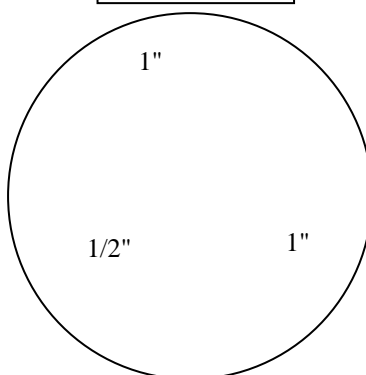
MnDOT: \_\_\_\_\_ Date: \_\_\_\_\_

# Mini-SID Visual Inspection Report Form

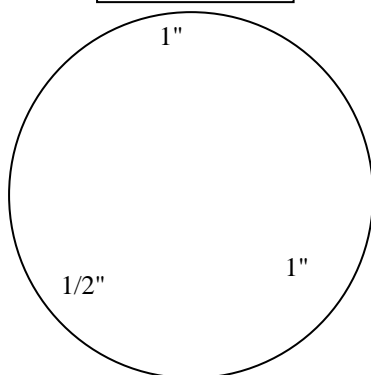
Project Name: <u>Baudette Bridge</u>	Shaft Number: <u>Technique Shaft</u>
Project Number: <u>180153</u>	Shaft Depth: <u>117.5'</u>
Drilling Contractor: <u>Veit</u>	Shaft Diameter: <u>8'</u>
Inspected By: <u>Allie Brady</u>	Date: <u>10/25/18</u>

Inspection #: <u>1</u>
Date: <u>10/25/18</u>
Start Time: <u>3:22</u>
Stop Time: <u>3:45</u>

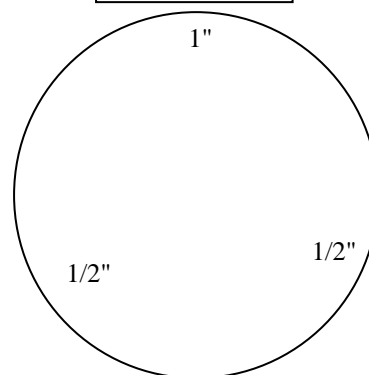
North View



West View

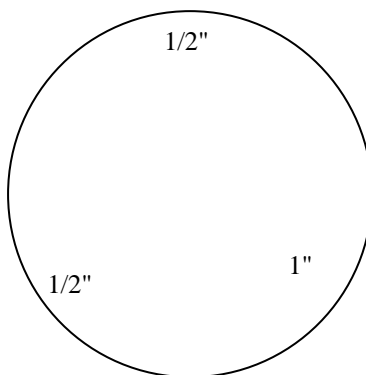


East View



Location	Limits Exceeded		
	Yes	No	
Center View	<input type="radio"/>	<input checked="" type="radio"/>	
North View	<input type="radio"/>	<input checked="" type="radio"/>	
East View	<input type="radio"/>	<input checked="" type="radio"/>	
South View	<input type="radio"/>	<input checked="" type="radio"/>	
West View	<input type="radio"/>	<input checked="" type="radio"/>	
Shaft Accepted	<input checked="" type="radio"/>	<input type="radio"/>	

1/2"



South View

Location	Acceptable %		
	Yes	No	
Shaft Accepted	<input checked="" type="radio"/>	<input type="radio"/>	
Center View %	100		
North View %	100		
East View %	100		
South View %	100		
West View %	100		

## Comments and Recommendations

Given By: \_\_\_\_\_

Given To: \_\_\_\_\_

Date: \_\_\_\_\_

Date: \_\_\_\_\_

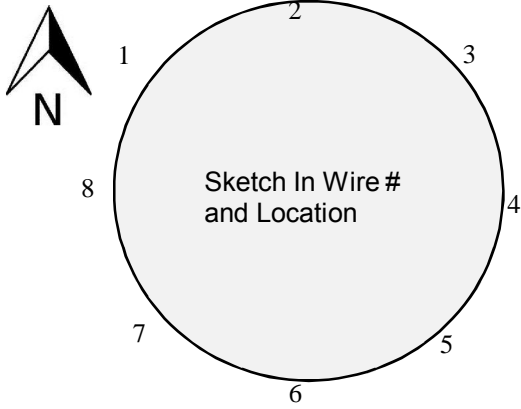
Notes: \_\_\_\_\_

\_\_\_\_\_  
Inspectors Signature: \_\_\_\_\_

# THERMAL FIELD LOG

Project Baudette Bridge  
Pier No. Technique shaft

Date Placed: 10/26/18  
Shaft No. 18



Wire #	Serial #	Extra wire length at load cell	Wire Length (#nodes)	Nodes Above Concrete	Wire Tested After Install
1	34725	0'	115	-	good
2	34726	11'			good
3	34723	9'			good
4	34724	11'			good
5	34719	14'			bad
6	34721	10'			good
7	34722	12'			good
8	34720	11'			good

PF

Wire-Wire Distance		
1-5 <u>7</u> in.	4-1 <u>7</u> in.	7-5 <u>4</u> in.
2-1 <u>4</u> in.	4-5 <u>5</u> in.	8-1 <u>8</u> in.
2-5 <u>0</u> in.	6-1 <u>4</u> in.	8-5 <u>6</u> in.
3-1 <u>9</u> in.	6-5 <u>3</u> in.	
3-5 <u>5</u> in.	7-1 <u>5</u> in.	

Shaft Information		
	Design	As-Built
Shaft Dia.	96 in.	96 in.
Shaft Length	111 ft.	11 ft.
Concrete Vol.	19 cy.	23 cy.
Cage Length	11 ft.	10 ft.
Cage Dia.	9 in.	9 in.
Casing Dia. (perm./temp.)	96 in.	96 in.
Casing Length	52 ft.	52 ft.
Reck Socket Dia.	90 in.	90* in.
Reck Socket Length	62 ft.	65.5 ft.

## Field Notes:

Start of Placement - 10/27/18

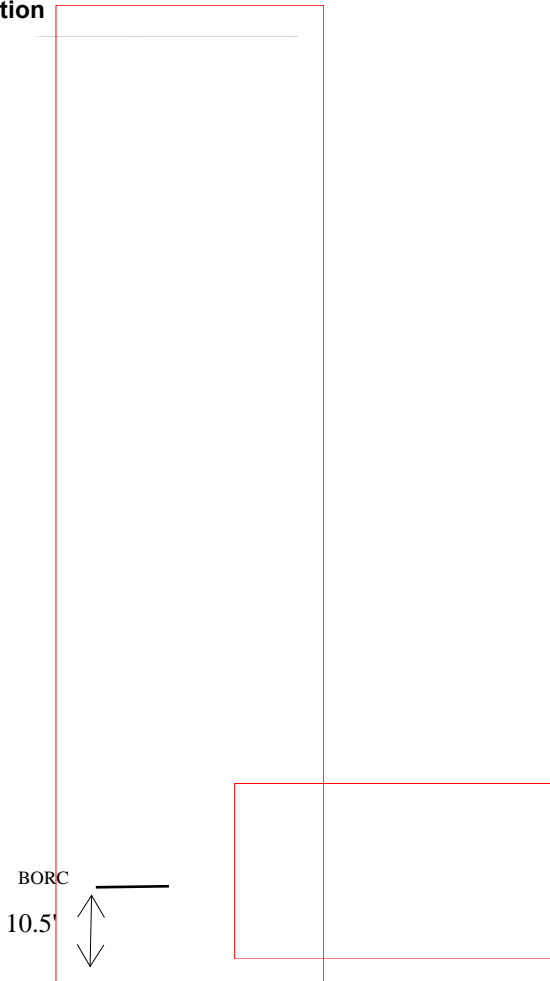
End of Placement - 10/27/18 3:30 pm

Placement Method - 2 pump trucks and tremie

\*\*socket diameter varies due to boulder obstruction removal

\*\*wires terminate at top of load cell. Extra wire length at top of load cell estimated in table above.

Elevation



## Legend

TOC	Top of Casing	BOC	Bottom of Casing
TOG	Top of Ground	BORC	Bottom of Reinf. Cage
TOS	Top of Shaft	BOS	Bottom of Shaft
TORS	Top of Rock Socket	▲	Water Level

Completed By: Allie Brady

Please Submit with Concrete Placement Log and Installation Record

8 Wire - Shaft

# Applied Foundation Testing

October 8, 2018

## Report of Drilled Shaft Dimensional Analysis

Baudette – Rainey River Bridge  
Test Shaft

AFT Project No.: 518053

### Authored By:



**Andrew Best**  
Staff Civil Engineer



**Jordan Nelson, P.E.**  
Mechanical Engineer

### Reviewed By:



**Donald T. Robertson, P.E.**  
Principal Geotechnical Engineer

For: **Allie Brady**  
Project Manager



**14000 Veit Place**  
**Rogers, MN 55374**  
Direct: 763-428-9558  
Cell: 612-221-1421  
Fax: 763-428-8348



# Report of Drilled Shaft Dimensional Analysis

General Information				
<b>Report Date:</b>	October 8, 2018			
<b>AFT Project No.:</b>	518053			
<b>Project Description:</b>	Baudette – Rainey River Bridge			
<b>Client Name:</b>	Veit & Company			
<b>Client Address:</b>	14000 Veit Place, Rogers, MN 55374			
<b>Client Contact:</b>	Allie Brady			
<b>Test Date:</b>	September 27, 2018 September 28, 2018			
<b>AFT Field Personnel:</b>		Donald T. Robertson, P.E., Andrew Best		
<b>AFT Responsible Engineer:</b>		Donald T. Robertson, P.E.		
Shaft Information <sup>1</sup>				
<b>Pier Number</b>	<b>Shaft Number</b>	<b>Diameter (in)</b>	<b>Length (ft)</b>	<b>Installation Date</b>
N/A	Test Shaft 1	96	116.5	N/A
<b>Top of Concrete Elevation (ft)</b>	<b>Shaft Tip Elevation (ft)</b>	<b>Nominal Volume (cu.yd)</b>	<b>As-Built Volume (cu.yd)</b>	<b>Volume Factor</b>
*1065.0	*951.0	N/A	N/A	N/A
Construction Information <sup>1</sup>				
<b>Drilling Method</b>				
<input type="checkbox"/> Dry	<input checked="" type="checkbox"/> Wet	<input type="checkbox"/> Cast-in-Place	<input type="checkbox"/> Other (specify)	
	<input type="checkbox"/> Natural/Water <input type="checkbox"/> Bentonite <input checked="" type="checkbox"/> Polymer	<input type="checkbox"/> Augered <input type="checkbox"/> Displacement <input type="checkbox"/> Other		
Casing				
<input checked="" type="checkbox"/> Permanent	Top Elev. (ft)	+1067.5	Length (ft)	52.0
			Diameter (in)	
<input checked="" type="checkbox"/> Temporary	Top Elev. (ft)	+1067.8	Length (ft)	40.0
			Diameter (in)	
<b>Installation Records provided to AFT</b>		<b>Soil Boring provided to AFT</b>		
<input type="checkbox"/> Yes <input type="checkbox"/> Attached <input checked="" type="checkbox"/> No		<input checked="" type="checkbox"/> Yes <input type="checkbox"/> Attached <input type="checkbox"/> No		



Testing Information				
<b>Included Analyses</b>		<b>Included Test Methods</b>		
<input type="checkbox"/> Inclination / Verticality <input checked="" type="checkbox"/> Cross Section <input type="checkbox"/> Sidewall Condition		<input type="checkbox"/> Thermal Integrity Profiling (TIP) <input checked="" type="checkbox"/> Mechanical Caliper <input type="checkbox"/> Gravity Inclinator <input type="checkbox"/> Acoustic Televiewer <input type="checkbox"/> Other: _____		
Test Method Description				
Data was collected using a 4-arm mechanical caliper device lowered to the bottom of the excavation, opened, and retrieved with a power winch.				
Results				
Profiles Attached				
<input type="checkbox"/> Temperature Profile <input checked="" type="checkbox"/> Radial Profile <input checked="" type="checkbox"/> Shape Render <input type="checkbox"/> Deviation Profile <input type="checkbox"/> Sidewall Imaging <input type="checkbox"/> Other:				
Inclination / Verticality				
Measured Length (ft)	Maximum Individual Verticality	Aggregate		
		Tendency (degrees)	Max Deviation (inches)	Verticality
112.5	Not Measured	N/A	N/A	N/A
Cross Sectional Analysis				
Depth Range (ft)	Avg Diameter (in) 09/27/18	Avg Diameter (in) 09/28/18	Comments	
0 - 52	94.5	94.5	Cased Zone	
52-112.5	93.8	96.4	Uncased Zone	

1. AFT was not under contract to document foundation construction. The information presented herein is for informational purposes only. Consult the original documentation for more information.

**Comments**

The average of 5 passes over the full length of the shaft on September 27th, 2018 and the average of 2 passes over the accessible length of the shaft on September 28th, 2018 are presented below.

**Closure**

We appreciate the opportunity to provide our services. If you have any questions relating to the content of this report please do not hesitate to contact us.

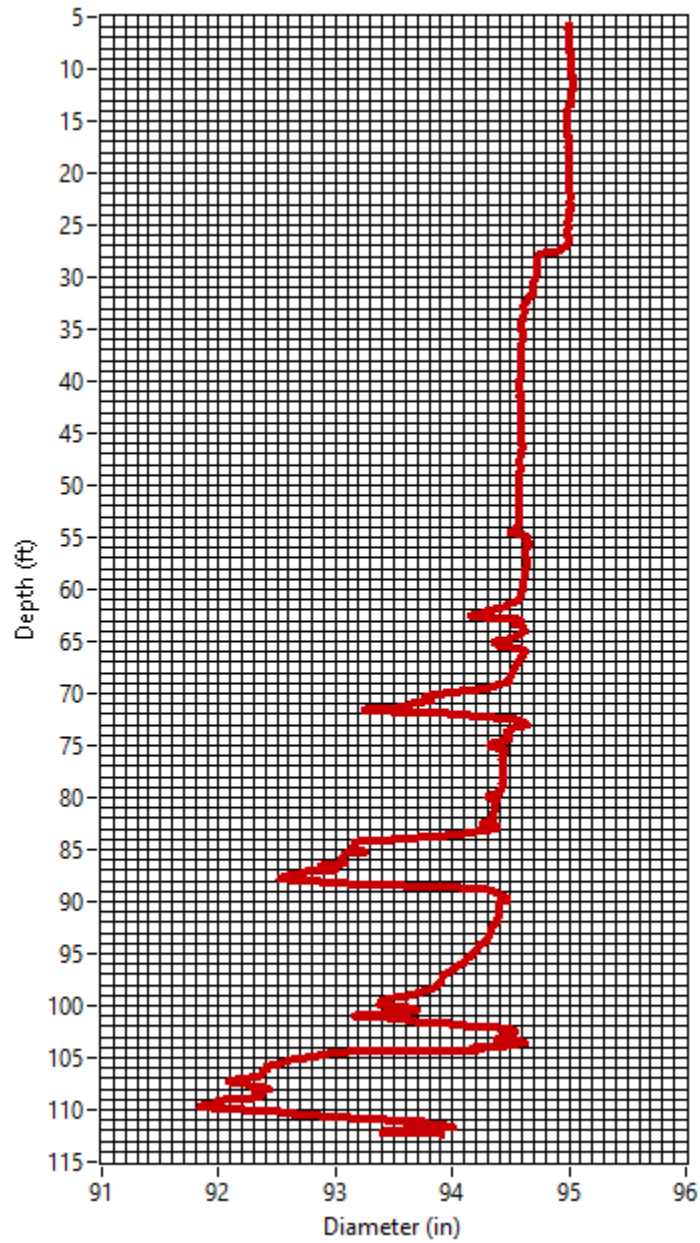
**Limitations**

This report presents test measurements made by AFT. Interpretations were made based upon the measurements made by AFT with the latest techniques available and currently accepted standards of care recognized by Geotechnical Engineering professionals. AFT is an independent agency and is not the Geotechnical Engineer of Record. The Geotechnical Engineer of Record should ultimately make final recommendations for foundation design and construction.



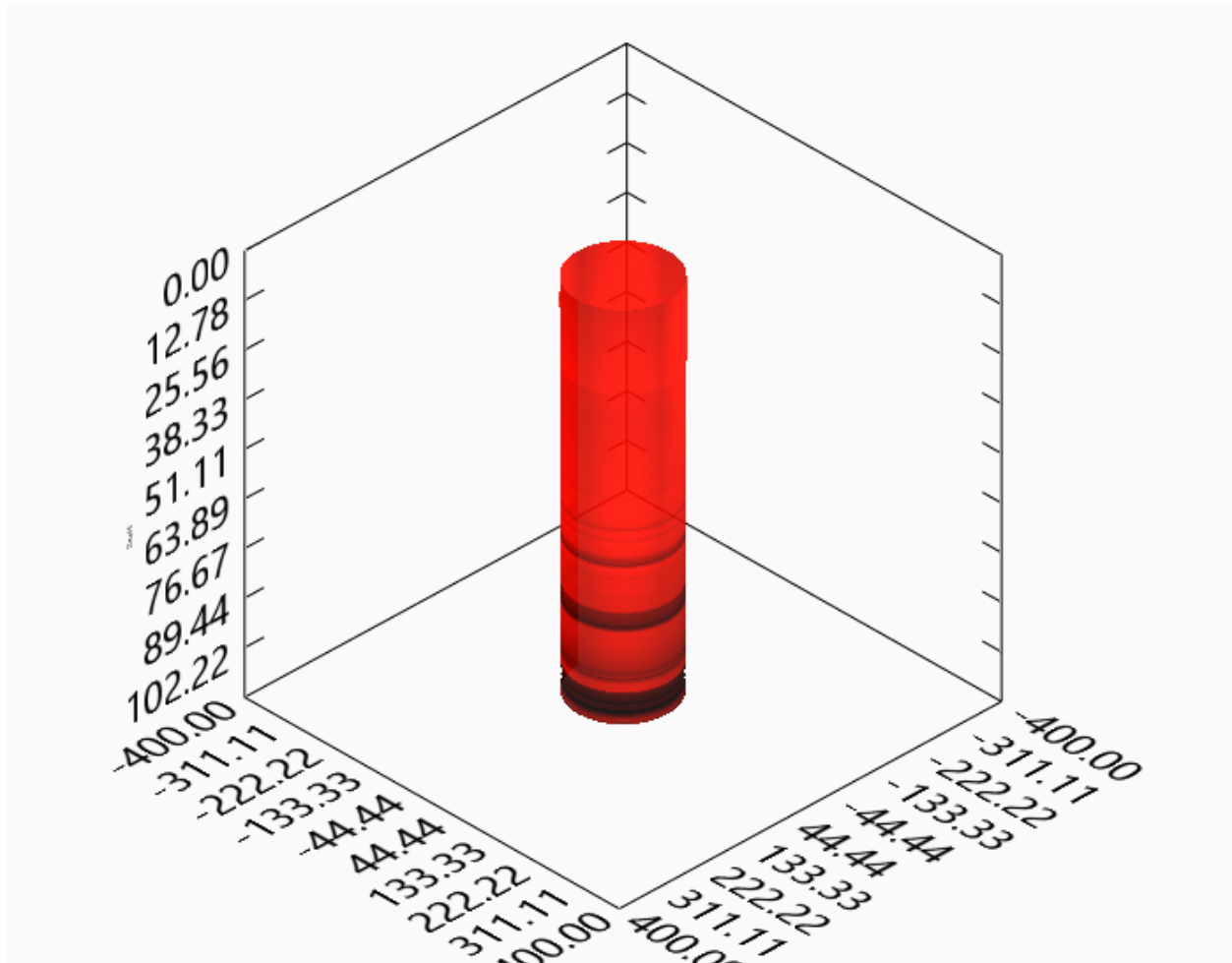


Radial Profile  
518053 Baudette – Rainey River Bridge – Test Shaft – September 27, 2018



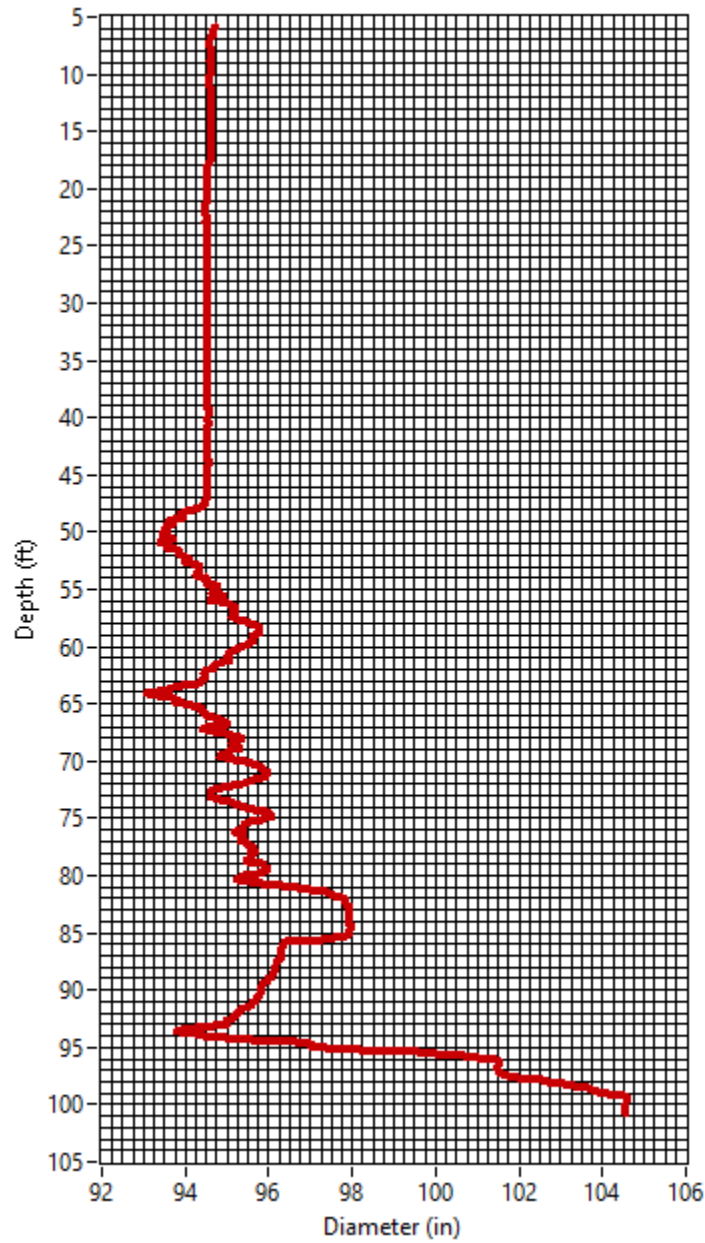


Shape Render  
518053 Baudette – Rainey River Bridge – Test Shaft – September 27, 2018



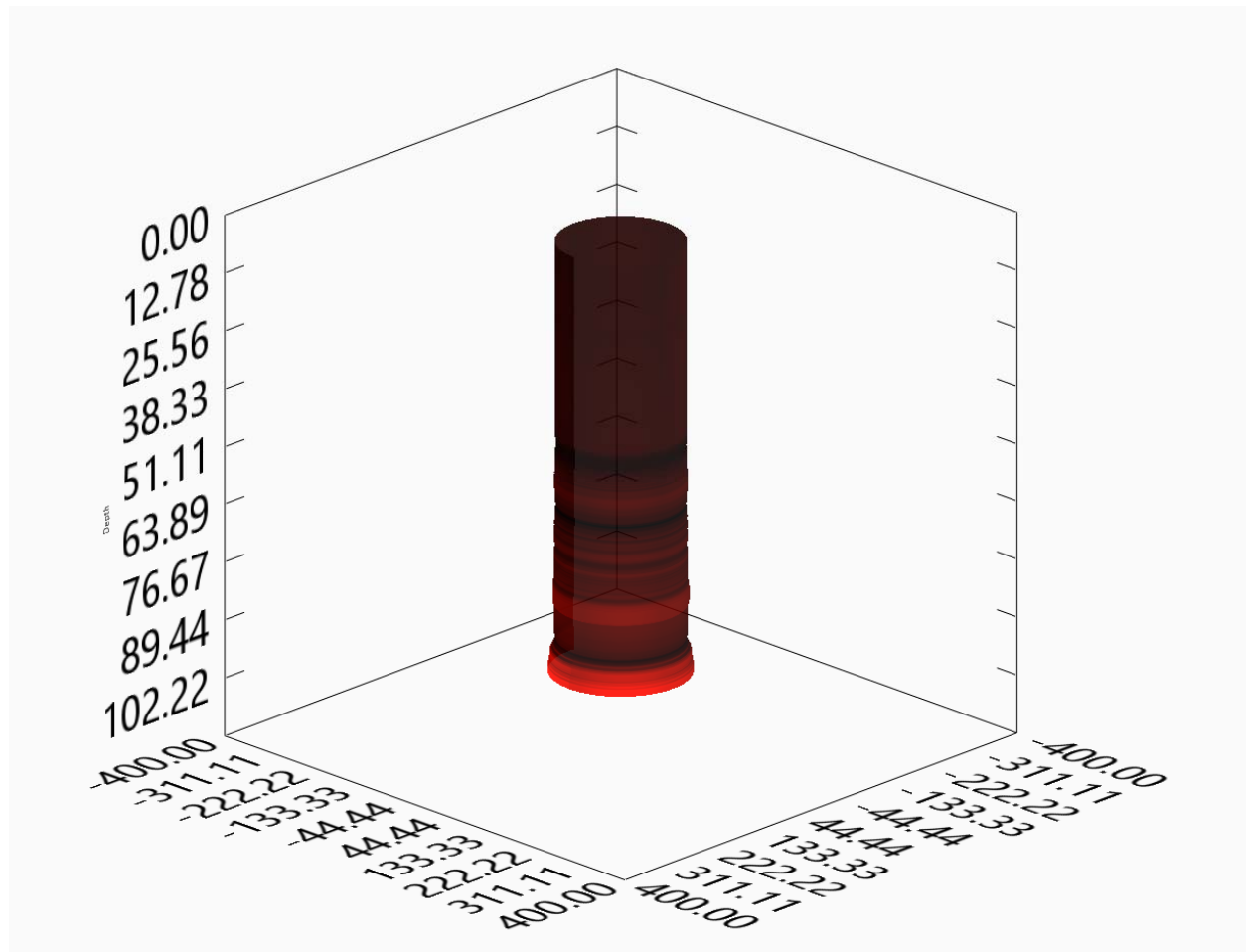


Radial Profile  
518053 Baudette – Rainey River Bridge – Test Shaft – September 28, 2018





Shape Render  
518053 Baudette – Rainey River Bridge – Test Shaft – September 28, 2018



# Applied Foundation Testing

October 31, 2018

## Report of Drilled Shaft Dimensional Analysis

Baudette – Rainey River Bridge  
Test Shaft

AFT Project No.: 518053

### Authored By:



**Andrew Best**  
Staff Civil Engineer



**Jordan Nelson, P.E.**  
Mechanical Engineer

### Reviewed By:



**Donald T. Robertson, P.E.**  
Principal Geotechnical Engineer

For: **Allie Brady**  
Project Manager



**14000 Veit Place**  
**Rogers, MN 55374**  
Direct: 763-428-9558  
Cell: 612-221-1421  
Fax: 763-428-8348



# Report of Drilled Shaft Dimensional Analysis

General Information				
<b>Report Date:</b>	October 31, 2018			
<b>AFT Project No.:</b>	518053			
<b>Project Description:</b>	Baudette – Rainey River Bridge			
<b>Client Name:</b>	Veit & Company			
<b>Client Address:</b>	14000 Veit Place, Rogers, MN 55374			
<b>Client Contact:</b>	Allie Brady			
<b>Test Date:</b>	October 25, 2018			
<b>AFT Field Personnel:</b>		Andrew Best		
<b>AFT Responsible Engineer:</b>		Donald T. Robertson, P.E.		
Shaft Information <sup>1</sup>				
<b>Pier Number</b>	<b>Shaft Number</b>	<b>Diameter (in)</b>	<b>Length (ft)</b>	<b>Installation Date</b>
N/A	Test Shaft 1	96	116.5	10/27/2018
<b>Top of Concrete Elevation (ft)</b>	<b>Shaft Tip Elevation (ft)</b>	<b>Nominal Volume (cu.yd)</b>	<b>As-Built Volume (cu.yd)</b>	<b>Volume Factor</b>
*1065.0	*948.5	See Records	See Records	See Records
Construction Information <sup>1</sup>				
<b>Drilling Method</b>				
<input type="checkbox"/> Dry	<input checked="" type="checkbox"/> Wet	<input type="checkbox"/> Cast-in-Place	<input type="checkbox"/> Other (specify)	
	<input type="checkbox"/> Natural/Water <input type="checkbox"/> Bentonite <input checked="" type="checkbox"/> Polymer	<input type="checkbox"/> Augered <input type="checkbox"/> Displacement <input type="checkbox"/> Other		
Casing				
<input checked="" type="checkbox"/> Permanent	Top Elev. (ft)	+1067.5	Length (ft)	52.0
			Diameter (in)	
<input checked="" type="checkbox"/> Temporary	Top Elev. (ft)	+1067.8	Length (ft)	40.0
			Diameter (in)	
<b>Installation Records provided to AFT</b>		<b>Soil Boring provided to AFT</b>		
<input type="checkbox"/> Yes <input type="checkbox"/> Attached <input checked="" type="checkbox"/> No		<input checked="" type="checkbox"/> Yes <input type="checkbox"/> Attached <input type="checkbox"/> No		



Testing Information				
<b>Included Analyses</b>		<b>Included Test Methods</b>		
<input type="checkbox"/> Inclination / Verticality <input checked="" type="checkbox"/> Cross Section <input type="checkbox"/> Sidewall Condition		<input type="checkbox"/> Thermal Integrity Profiling (TIP) <input checked="" type="checkbox"/> Mechanical Caliper <input type="checkbox"/> Gravity Inclinator <input type="checkbox"/> Acoustic Televiewer <input type="checkbox"/> Other: _____		
Test Method Description				
Data was collected using a 4-arm mechanical caliper device lowered to the bottom of the excavation, opened, and retrieved with a power winch.				
Results				
Profiles Attached				
<input type="checkbox"/> Temperature Profile <input checked="" type="checkbox"/> Radial Profile <input checked="" type="checkbox"/> Shape Render <input type="checkbox"/> Deviation Profile <input type="checkbox"/> Sidewall Imaging <input type="checkbox"/> Other:				
Inclination / Verticality				
Measured Length (ft)	Maximum Individual Verticality	Aggregate		
		Tendency (degrees)	Max Deviation (inches)	Verticality
114.0	Not Measured	N/A	N/A	N/A
Cross Sectional Analysis				
Depth Range (ft)	Avg Diameter (in) 10/25/18	Comments		
0 - 52	95.4	Cased Zone		
52-114.0	97.2	Uncased Zone		

1. AFT was not under contract to document foundation construction. The information presented herein is for informational purposes only. Consult the original documentation for more information.

**Comments**

The average of 3 passes over the full length of the shaft on October 25th, 2018 are presented below.

**Closure**

We appreciate the opportunity to provide our services. If you have any questions relating to the content of this report, please do not hesitate to contact us.

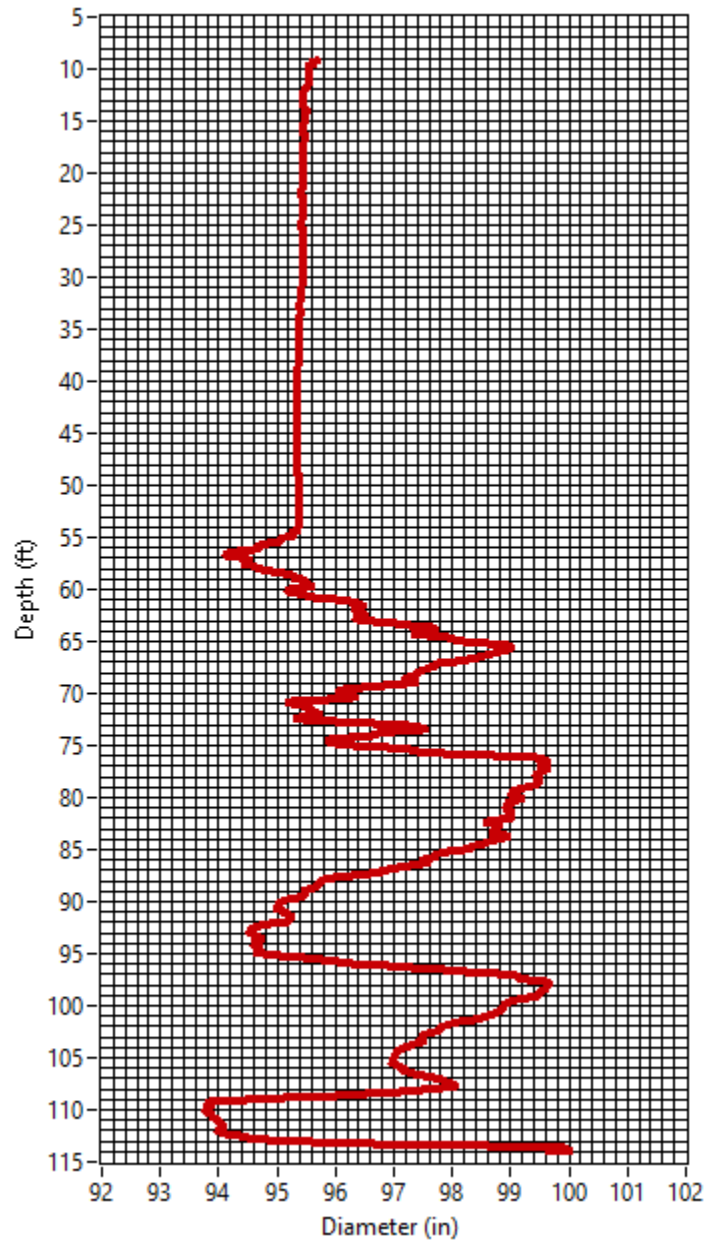
**Limitations**

This report presents test measurements made by AFT. Interpretations were made based upon the measurements made by AFT with the latest techniques available and currently accepted standards of care recognized by Geotechnical Engineering professionals. AFT is an independent agency and is not the Geotechnical Engineer of Record. The Geotechnical Engineer of Record should ultimately make final recommendations for foundation design and construction.



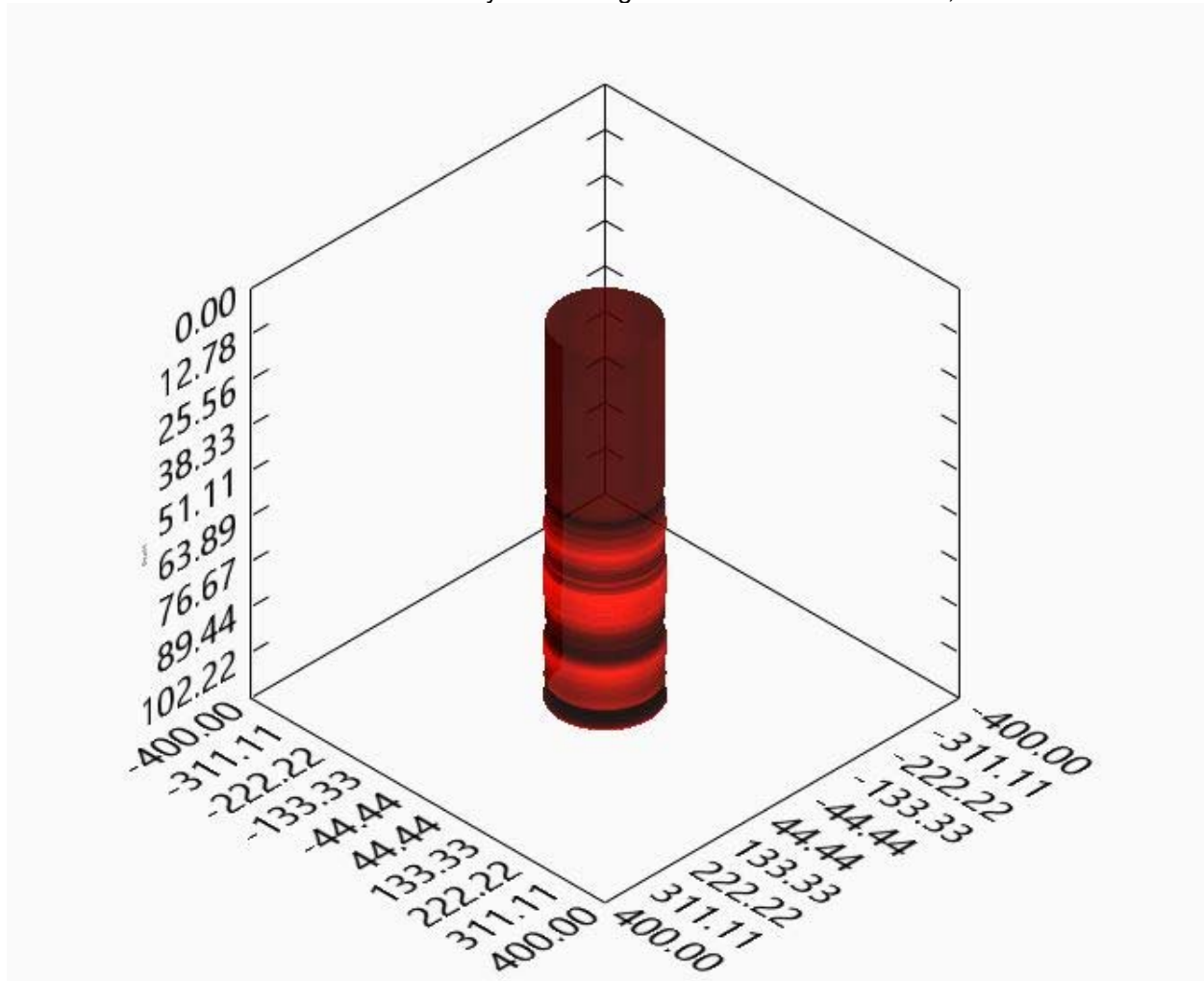


Radial Profile  
518053 Baudette – Rainey River Bridge – Test Shaft – October 25, 2018

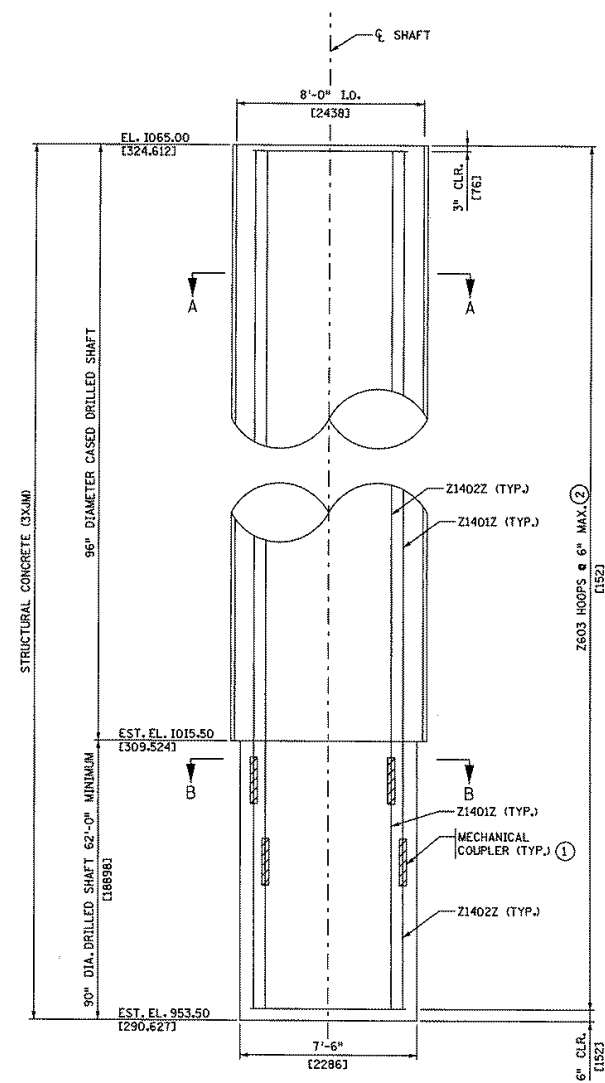




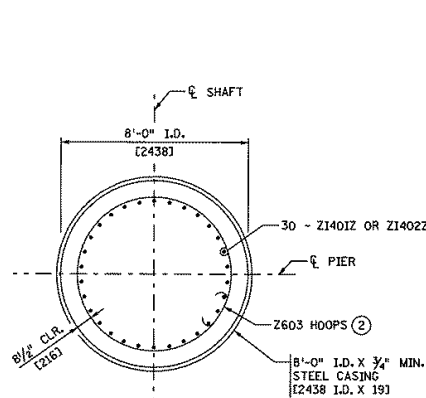
Shape Render  
518053 Baudette – Rainey River Bridge – Test Shaft – October 25, 2018



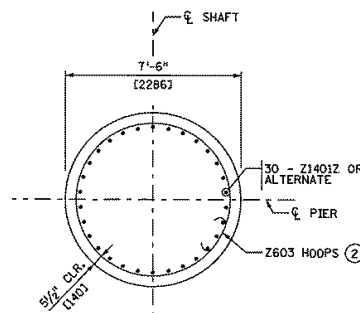
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Date Plotted: 13-NOV-2017  
Time Plotted: 2:42:07 PM  
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File Path: 030-TechniqueShaft.d1r.dgn



ELEVATION



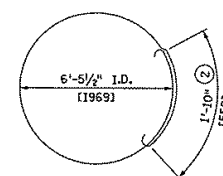
SECTION A-A



SECTION B-B

Z1401Z & Z1402Z BAR LAYOUT

BARS UNIFORMLY DISTRIBUTED  
AROUND PERIMETER AS SHOWN



Z603  
HOOPS

BILL OF REINFORCEMENT  
TECHNIQUE SHAFT

BAR	NO.	LENGTH	SHAPE	LOCATION
Z1401Z	30	60'-0" [18288]	-----	VERTICAL
Z1402Z	30	51'-6" [15697]	-----	VERTICAL
Z603	223	23'-8" [7204]	○	HOOPS

PAYMENT TO BE INCLUDED IN PRICE BID FOR "TECHNIQUE SHAFT".

### NOTES:

CONSTRUCT TECHNIQUE SHAFT PER DRILLED SHAFT REQUIREMENTS IN THE SPECIAL PROVISIONS AND THESE PLANS. FOR DRILLED SHAFT INFORMATION, REQUIREMENTS AND TESTING SEE SPECIAL PROVISIONS.

LOCATE TEST SHAFT NEAR PIERS 2, 3 OR 4 AND WITHIN 20 FEET [6096] OF BORING THAT EXTENDS AT LEAST 15 FT [4572] BELOW THE TIP OF THE SHAFT. LOCATE SHAFT A MINIMUM OF 24 FEET [7315] FROM ANY PERMANENT FOUNDATION ELEMENT.

CONTRACTOR TO SUBMIT A DETAILED INSTALLATION PLAN AND PROCEDURES TO ESTABLISH THE BASIS FOR PRODUCTION SHAFT INSTALLATION TO THE ENGINEER FOR ACCEPTANCE.

THE GEOTECHNICAL ENGINEER, OR THEIR REPRESENTATIVE ON SITE, WILL DETERMINE THE FINAL TIP ELEVATION DURING SHAFT EXCAVATION. DURING EXCAVATION, THE GEOTECHNICAL ENGINEER WILL DETERMINE IF A CHANGE TO THE TIP ELEVATION IS NECESSARY ON THE BASIS OF OBSERVATION OF THE EXCAVATED MATERIALS. THE GEOTECHNICAL ENGINEER WILL COORDINATE WITH THE ENGINEER REGARDING NECESSARY CHANGES AND THE ENGINEER WILL TRANSMIT REVISED SHAFT LENGTH AND TIP ELEVATION TO THE CONTRACTOR.

THERMAL INTEGRITY PROFILE TESTING (TIP) TO BE CONDUCTED IN ACCORDANCE WITH THE SPECIAL PROVISIONS.

PERFORM STATIC LOAD TEST (BI-DIRECTION STATIC LOAD) PER SPECIAL PROVISIONS AND THESE PLANS.

- POSITION ONE LEVEL BI-DIRECTIONAL LOADING SYSTEM CAPABLE OF PRODUCING 8,000 KIP [35960 kN] OF UNIAXIAL FORCE APPROXIMATELY 10 FEET [3048] ABOVE THE BASE.

- PROVIDE FIVE LEVELS OF STRAIN GAUGES IN SHAFT WITH FOUR GAGES PER LEVEL (TOTAL 20)

- CONDUCT TEST IN GENERAL ACCORDANCE WITH ASTM D1143 PROCEDURE A, QUICK TEST.

DO NOT BEGIN SHAFT CONSTRUCTION WITHOUT APPROVAL BY THE ENGINEER. CONSTRUCTION OF PERMANENT PRODUCTION SHAFTS NOT TO BEGIN UNTIL TECHNIQUE SHAFT IS CONSTRUCTED AND STATIC LOAD TEST IS COMPLETED.

REMOVE TECHNIQUE SHAFT TO AN ELEVATION 2 FEET [610] BELOW THE MUDLINE.

DO NOT PLACE REINFORCEMENT OR CONCRETE IN SHAFTS WITHOUT APPROVAL OF THE ENGINEER.

REINFORCEMENT LENGTH SHOWN IS BASED ON MINIMUM SHAFT LENGTHS. ADJUST LENGTHS BASED ON ACTUAL SHAFT TIP ELEVATIONS. SEE SPECIAL PROVISIONS FOR PAYMENT INFORMATION.

THE SERVICES OF AN APPROVED BI-DIRECTIONAL STATIC LOAD TEST SUPPLIER MUST BE ENGAGED FOR INSTRUMENTING, PERFORMING, AND REPORTING OF THE LOAD TEST. THE CONTRACTOR MUST SUBCONTRACT WITH THE BI-DIRECTION STATIC LOAD TEST MANUFACTURER TO SUPPLY THE LOAD TEST CELLS AND OTHER NECESSARY EQUIPMENT AND INSTRUMENTATION, PERFORM THE TEST, AND ANALYZE THE RESULTS.

REINFORCING CAGE SUPPORT AND REINFORCING BI-DIRECTIONAL LOADING SYSTEM TIE-IN TO BE AS INDICATED ON THE APPROVED SHOP DRAWINGS DEVELOPED BY THE BI-DIRECTIONAL STATIC LOAD TEST SUPPLIER.

① STAGGER COUPLER LOCATIONS ON ADJACENT BARS 3'-0" [914] MIN.

② ALTERNATE LAP SPLICE LOCATION 180° ON EACH HOOP.

REV. NO.	DATE	REVISION DESCRIPTION	APPROVED

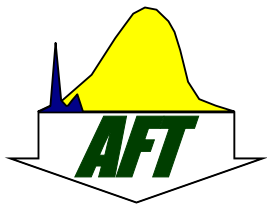
**PARSONS**

CERTIFIED BY *Bradley J. Berg* 11/14/17  
LICENSED PROFESSIONAL ENGINEER  
NAME: BRADLEY J. BERG LIC. NO. 46636

TITLE: TECHNIQUE SHAFT

DESIGN: EJA  
CHECK: ASP  
APPROVED: 12/4/17  
SHEET NO. 30 OF 123 SHEETS

BRIDGE NO. 39016



## **Appendix C Calibrations**

### **Report of Bi-Directional Load Testing – Test Shaft**

Rainy River Bridge  
Baudette, Minnesota

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# Applied Foundation Testing, Inc.

4035 J. Louis Street  
Green Cove Springs, FL 32043  
P: (904) 284-1337  
F: (904) 284-1339

## AFT-Cell® Calibration Report

Calibration Date 1/16/2018

Technician Ryan Wendlandt

Ambient 59.0°F

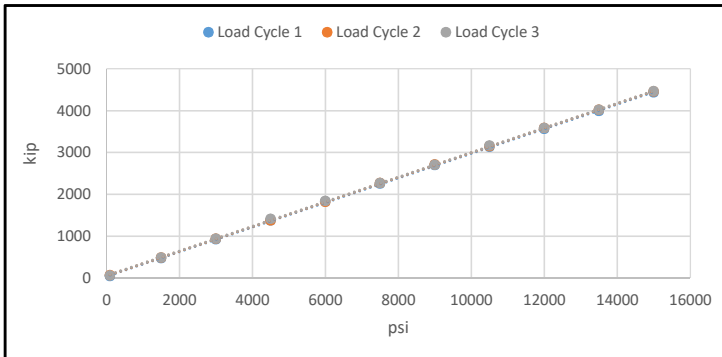
Description 24 inch AFT-Cell

Model AFT-Cell® Model 24

Serial Number AFT24-068

Uni-Directional Range 4400 kip

Bi-Directional  
Equivalent Range 8800 kip



Calibrating Equipment		
Item	Description	Serial
Pressure Gauge	20000 PSIG	1659929
Load Reference	14MN	C3929-13
Data Acquisition	NI 9219	1A4225C
Load Frame	HULC 10000 KIP	N/A

Load Cycle 1		Load Cycle 2		Load Cycle 3		Nonlinearity (%)
Stroke (in):	2.00	Stroke (in):	4.00	Stroke (in):	5.00	
Reference (kip)	Pressure (psig)	Reference (kip)	Pressure (psig)	Reference (kip)	Pressure (psig)	
48	100	67	100	64	100	0.74%
476	1500	489	1500	489	1500	0.36%
921	3000	940	3000	943	3000	0.28%
1372	4500	1378	4500	1410	4500	0.05%
1823	6000	1819	6000	1845	6000	-0.18%
2254	7500	2270	7500	2270	7500	0.05%
2695	9000	2711	9000	2708	9000	0.05%
3134	10500	3150	10500	3166	10500	0.09%
3559	12000	3581	12000	3581	12000	0.46%
3990	13500	4019	13500	4019	13500	0.68%
4435	15000	4451	15000	4461	15000	0.59%

Comments:

Linear Jack Factor 0.2940 kip/psig

Regression Zero 51.1436 kip

Maximum Nonlinearity 0.74%

Applied Foundation Testing, Inc. hereby certifies that this instrument meets or exceeds all requirements for its intended use and the reported calibration factors are accurate to within the limits of the calibrating procedure. Reference standards and calibrations are traceable to the National Institute of Standards and Technology (NIST) where applicable.

Technician: Ryan Wendlandt

Approved: [Signature]



# Applied Foundation Testing, Inc.

4035 J. Louis Street  
Green Cove Springs, FL 32043  
P: (904) 284-1337  
F: (904) 284-1339

## AFT-Cell® Calibration Report

Calibration Date 7/2/2018

Technician Austin Robertson

Ambient 83.5°F

*Held in Readiness prior to installation. Calibration interval is 6 months after release used as a reusable jack*

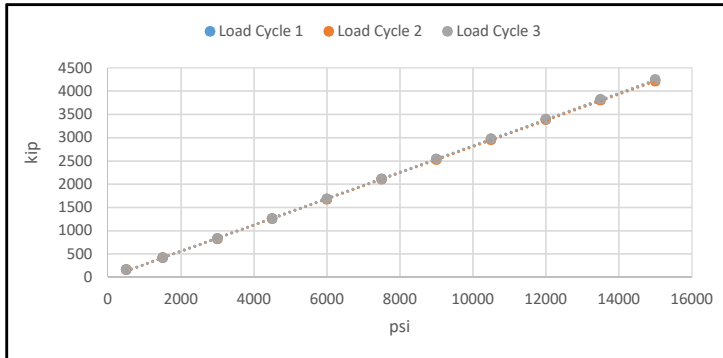
Description 24 inch AFT-Cell

Model AFT-Cell® Model 24

Serial Number AFT24-071SF

Uni-Directional Range 4400 kip

Bi-Directional Equivalent Range 8800 kip



Calibrating Equipment		
Item	Description	Serial
Pressure Reference	Ashcroft 20kpsi	1659929
Load Reference (1)	Geokon Model 3000	1800247
Load Reference (2)	Geokon Model 3000	1800248
Load Reference (3)	Geokon Model 3000	1800249
Data Acquisition (1)	NI 9219	16987A4
Data Acquisition (2)	NI 9219	1488699
Load Frame	HULC 10000 kip	N/A

Load Cycle 1		Load Cycle 2		Load Cycle 3		Nonlinearity (%)
Stroke (in):	1.50	Stroke (in):	3.50	Stroke (in):	5.50	
Reference (kip)	Pressure (psig)	Reference (kip)	Pressure (psig)	Reference (kip)	Pressure (psig)	
160	500	164	500	163	500	-0.54%
421	1500	418	1500	417	1500	-0.06%
829	3000	819	3000	829	3000	0.29%
1255	4500	1257	4500	1256	4500	0.23%
1680	6000	1672	6000	1687	6000	0.20%
2110	7500	2102	7500	2106	7500	0.04%
2537	9000	2526	9000	2538	9000	-0.04%
2967	10500	2950	10500	2975	10500	-0.19%
3390	12000	3380	12000	3390	12000	-0.18%
3810	13500	3800	13500	3820	13500	-0.10%
4230	15000	4210	15000	4250	15000	-0.03%

Comments:

Linear Jack Factor 0.2822 kip/psig

Regression Zero -4.9049 kip

Maximum Nonlinearity -0.54%

Applied Foundation Testing, Inc. hereby certifies that this instrument meets or exceeds all requirements for its intended use and the reported calibration factors are accurate to within the limits of the calibrating procedure. Reference standards and calibrations are traceable to the National Institute of Standards and Technology (NIST) where applicable.

Technician:

Approved:



# Applied Foundation Testing, Inc.

4035 J. Louis Street  
Green Cove Springs, FL 32043  
P: (904) 284-1337  
F: (904) 284-1339

## AFT-Cell® Calibration Report

Calibration Date 5/8/2018

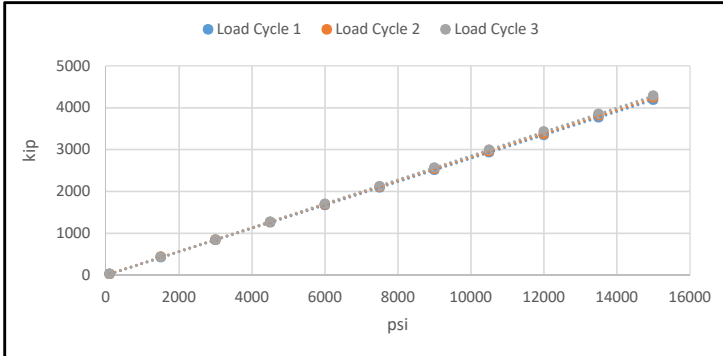
Technician Austin Robertson

Ambient 84.9°F

*Held in Readiness prior to installation. Calibration interval is 6 months after release used as a reusable jack*

Description 24 inch AFT-Cell  
Model AFT-Cell® Model 24  
Serial Number AFT24-092SF  
Uni-Directional Range 4400 kip  
Bi-Directional Equivalent Range 8800 kip

Calibrating Equipment		
Item	Description	Serial
Pressure Reference	Ashcroft 20kpsi	1659929
Load Reference (1)	Geokon Model 3000	1800247
Load Reference (2)	Geokon Model 3000	1800248
Load Reference (3)	Geokon Model 3000	1800249
Data Acquisition (1)	NI 9219	16987A4
Data Acquisition (2)	NI 9219	1488699
Load Frame	HULC 10000 kip	N/A



Load Cycle 1		Load Cycle 2		Load Cycle 3		Nonlinearity (%)
Reference (kip)	Pressure (psig)	Reference (kip)	Pressure (psig)	Reference (kip)	Pressure (psig)	
31	100	31	100	33	100	-0.03%
429	1500	444	1500	437	1500	-0.10%
841	3000	845	3000	847	3000	0.15%
1258	4500	1270	4500	1274	4500	0.29%
1674	6000	1690	6000	1702	6000	0.45%
2090	7500	2111	7500	2127	7500	0.61%
2511	9000	2535	9000	2567	9000	0.65%
2937	10500	2960	10500	2993	10500	0.59%
3350	12000	3370	12000	3430	12000	0.81%
3770	13500	3810	13500	3850	13500	0.88%
4190	15000	4240	15000	4290	15000	0.95%

Comments:

Linear Jack Factor 0.2820 kip/psig  
Regression Zero 1.5510 kip  
Maximum Nonlinearity 0.95%

Applied Foundation Testing, Inc. hereby certifies that this instrument meets or exceeds all requirements for its intended use and the reported calibration factors are accurate to within the limits of the calibrating procedure. Reference standards and calibrations are traceable to the National Institute of Standards and Technology (NIST) where applicable.

Technician: Ryan Wendlandt

Approved: John P. [Signature]



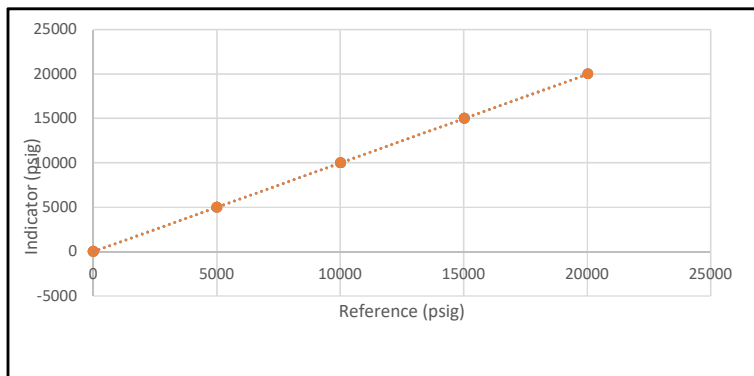
# Applied Foundation Testing, Inc.

2345 Success Drive  
Odessa, FL 33556  
P: (727) 376-5040  
F: (727) 376-5018

## Pressure Indicator Calibration Report

Calibration Date 8/9/2018  
Calibration Due 8/9/2019  
Technician N. Holmberg  
Ambient 35°C 46%RH

Description Ashcroft Digital Pressure Gauge  
Model DG25  
Serial Number 18080120011  
Range 20000 psig



Calibrating Equipment		
Item	Description	Serial
Pressure Reference	CEJN 30kpsi	CP285481
20kpsi Pressure Ref	Ashcroft 20k 0.5%	504150025
30kpsi Hand Pump	Enerpac HPN2000	N/A

Pressure Cycle 1			Pressure Cycle 2			Average
Reference (psig)	Found As (psig)	Left As (psig)	Reference (psig)	Found As (psig)	Left As (psig)	Nonlinearity (%)
0	0	0	0	0	0	0.00%
5000	5000	5000	5000	5008	5008	-0.02%
10000	10013	10013	10000	10014	10014	-0.02%
15000	15028	15028	15000	15024	15024	0.00%
20000	20036	20036	20000	20033	20033	0.00%
15000	15030	15030	15000	15028	15028	0.01%
10000	10019	10019	10000	10018	10018	0.01%
5000	5012	5012	5000	5010	5010	0.01%
0	3	3	0	3	3	0.01%

Linear Gage Factor 0.9983 psig/psig  
Regression Zero -0.1837 psig

Maximum Nonlinearity -0.02%

Applied Foundation Testing, Inc. hereby certifies that this instrument meets or exceeds all requirements for its intended use and the reported calibration factors are accurate to within the limits of the calibrating procedure. Reference standards and calibrations are traceable to the National Institute of Standards and Technology (NIST) where applicable.

Technician:

Approved:





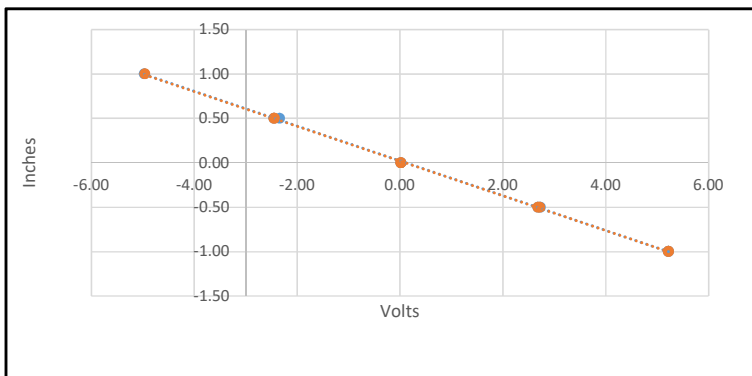
# Applied Foundation Testing, Inc.

2345 Success Drive  
Odessa, FL 33556  
P: (727) 376-5040  
F: (727) 376-5018

## Displacement Transducer Calibration Report

Calibration Date 8/6/2018  
Calibration Due 8/6/2019  
Technician K. Shaw  
Ambient 20C 55%RH

Description Omega 2in LVDTs  
Model LD620-25  
Serial Number M930415x-03  
Range 2 in



Calibrating Equipment		
Item	Description	Serial
Data Acquisition	NI 9219	1A4225C
Traceable Rule	Fowler 12 inch	251010207

Displacement Cycle 1			Displacement Cycle 2			Average
Reference (in)	Found As (VDC)	Left As (VDC)	Reference (in)	Found As (VDC)	Left As (VDC)	Nonlinearity (%)
-1.00	5.22	5.22	-1.00	5.22	5.22	-0.06%
-0.50	2.68	2.68	-0.50	2.72	2.72	-0.38%
0.00	0.02	0.02	0.00	0.02	0.02	0.86%
0.50	-2.34	-2.34	0.50	-2.45	-2.45	-0.49%
1.00	-4.97	-4.97	1.00	-4.96	-4.96	-0.32%
0.50	-2.45	-2.45	0.50	-2.44	-2.44	0.00%
0.00	0.02	0.02	0.00	0.02	0.02	0.86%
-0.50	2.73	2.73	-0.50	2.68	2.68	-0.43%
-1.00	5.22	5.22	-1.00	5.22	5.22	-0.06%

Linear Gage Factor -0.1958 in/V  
Regression Zero 0.0212 in

Maximum Nonlinearity 0.86%

Sensitivity -10.1040 V

Applied Foundation Testing, Inc. hereby certifies that this instrument meets or exceeds all requirements for its intended use and the reported calibration factors are accurate to within the limits of the calibrating procedure. Reference standards and calibrations are traceable to the National Institute of Standards and Technology (NIST) where applicable.

Technician: *Kathleen Shaw*

Approved: *John P. [Signature]*



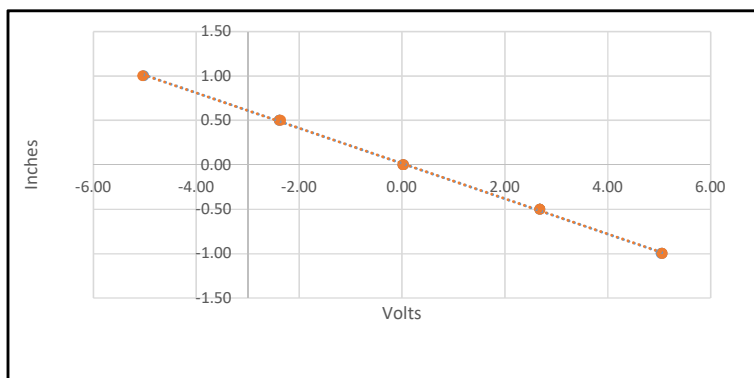
# Applied Foundation Testing, Inc.

2345 Success Drive  
Odessa, FL 33556  
P: (727) 376-5040  
F: (727) 376-5018

## Displacement Transducer Calibration Report

Calibration Date 8/6/2018  
Calibration Due 8/6/2019  
Technician K. Shaw  
Ambient 20C 55%RH

Description Omega 2in LVDTs  
Model LD620-25  
Serial Number M930415x-04  
Range 2 in



Calibrating Equipment		
Item	Description	Serial
Data Acquisition	NI 9219	1A4225C
Traceable Rule	Fowler 12 inch	251010207

Displacement Cycle 1			Displacement Cycle 2			Average
Reference (in)	Found As (VDC)	Left As (VDC)	Reference (in)	Found As (VDC)	Left As (VDC)	Nonlinearity (%)
-1.00	5.04	5.04	-1.00	5.06	5.06	0.59%
-0.50	2.68	2.68	-0.50	2.68	2.68	-0.85%
0.00	0.03	0.03	0.00	0.02	0.02	0.54%
0.50	-2.38	-2.38	0.50	-2.36	-2.36	-0.67%
1.00	-5.02	-5.02	1.00	-5.04	-5.04	0.77%
0.50	-2.38	-2.38	0.50	-2.38	-2.38	-0.57%
0.00	0.02	0.02	0.00	0.03	0.03	0.55%
-0.50	2.68	2.68	-0.50	2.68	2.68	-0.85%
-1.00	5.06	5.06	-1.00	5.06	5.06	0.49%

Linear Gage Factor -0.1988 in/V  
Regression Zero 0.0156 in

Maximum Nonlinearity -0.85%

Sensitivity -9.9837 V

Applied Foundation Testing, Inc. hereby certifies that this instrument meets or exceeds all requirements for its intended use and the reported calibration factors are accurate to within the limits of the calibrating procedure. Reference standards and calibrations are traceable to the National Institute of Standards and Technology (NIST) where applicable.

Technician:

Approved:



48 Spencer St. Lebanon, NH 03766 USA

## Vibrating Wire Displacement Transducer Calibration Report

Model: 4450AFT-230MMCalibration Date: June 25, 2018Serial Number: 1820686This calibration has been verified/validated as of 06/26/2018Temperature: 23.5 °CCalibration Instruction: CI-4400Technician: Kathy RogersCable Length: N/A

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2899	2899	2899	-0.22	-0.09	0.04	0.02
46.0	3959	3960	3960	45.98	-0.01	45.93	-0.03
92.0	5022	5020	5021	92.23	0.10	92.02	0.01
138.0	6074	6078	6076	138.19	0.08	137.99	-0.01
184.0	7130	7130	7130	184.10	0.04	184.06	0.02
230.0	8176	8178	8177	229.72	-0.12	229.97	-0.01

(mm) Linear Gage Factor (G): 0.04356 (mm/digit)Regression Zero: 2904Polynomial Gage Factors: A: 6.8034E-08 B: 0.04281 C: Calculate C by setting D = 0 and  $R_1$  = initial field zero reading into the polynomial equation(inches) Linear Gage Factor (G): 0.001715 (inches/digit)Polynomial Gage Factors: A: 2.6785E-09 B: 0.001685 C: Calculate C by setting D = 0 and  $R_1$  = initial field zero reading into the polynomial equationCalculated Displacement: Linear,  $D = G (R_1 - R_0)$ 

$$\text{Polynomial, } D = AR_1^2 + BR_1 + C$$

Refer to manual for temperature correction information.

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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## Vibrating Wire Displacement Transducer Calibration Report

Model: 4450AFT-230MM

Calibration Date: June 25, 2018

This calibration has been verified/validated as of 06/26/2018

Serial Number: 1820687

Temperature: 23.5 °C

Calibration Instruction: CI-4400

Technician: Kathy Rogers

Cable Length: N/A

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	3052	3054	3053	-0.39	-0.17	0.02	0.01
46.0	4119	4117	4118	46.05	0.02	45.96	-0.02
92.0	5179	5181	5180	92.36	0.16	92.03	0.01
138.0	6234	6232	6233	138.28	0.12	137.95	-0.02
184.0	7284	7285	7285	184.13	0.06	184.05	0.02
230.0	8326	8327	8327	229.57	-0.19	229.98	-0.01

(mm) Linear Gage Factor (G): 0.04361 (mm/digit)

Regression Zero: 3062

Polynomial Gage Factors: A: 1.0987E-07 B: 0.04236 C:                     

Calculate C by setting D = 0 and R<sub>1</sub> = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001717 (inches/digit)

Polynomial Gage Factors: A: 4.3254E-09 B: 0.001668 C:                     

Calculate C by setting D = 0 and R<sub>1</sub> = initial field zero reading into the polynomial equation

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

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

Refer to manual for temperature correction information.

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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## Vibrating Wire Displacement Transducer Calibration Report

Model: 4450AFT-230MM

Calibration Date: June 25, 2018

This calibration has been verified/validated as of 06/26/2018

Serial Number: 1820688

Temperature: 23.5 °C

Calibration Instruction: CI-4400

Technician:

Cable Length: N/A

*Kathy Rogers*

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2847	2847	2847	-0.34	-0.15	-0.01	0.00
46.0	3927	3928	3928	46.06	0.02	45.99	-0.01
92.0	5003	5008	5006	92.35	0.15	92.08	0.03
138.0	6072	6074	6073	138.19	0.08	137.92	-0.03
184.0	7142	7141	7142	184.07	0.03	184.01	0.00
230.0	8203	8204	8204	229.68	-0.14	230.01	0.00

(mm) Linear Gage Factor (G): 0.04294 (mm/digit)

Regression Zero: 2855

Polynomial Gage Factors: A: 8.7209E-08 B: 0.04198 C:

Calculate C by setting D = 0 and  $R_1$  = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001691 (inches/digit)

Polynomial Gage Factors: A: 3.4334E-09 B: 0.001653 C:

Calculate C by setting D = 0 and  $R_1$  = initial field zero reading into the polynomial equation

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

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

Refer to manual for temperature correction information.

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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## Vibrating Wire Displacement Transducer Calibration Report

Model: 4450AFT-230MM

Calibration Date: June 25, 2018

This calibration has been verified/validated as of 06/26/2018

Serial Number: 1820689

Temperature: 23.5 °C

Calibration Instruction: CI-4400

Technician: Kathy Rogers

Cable Length: N/A

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2880	2876	2878	-0.52	-0.23	-0.03	-0.02
46.0	3953	3957	3955	46.19	0.08	46.10	0.05
92.0	5016	5018	5017	92.25	0.11	91.89	-0.05
138.0	6082	6081	6082	138.42	0.18	138.06	0.03
184.0	7134	7133	7134	184.05	0.02	183.97	-0.01
230.0	8183	8181	8182	229.52	-0.21	230.01	0.00

(mm) Linear Gage Factor (G): 0.04337 (mm/digit)

Regression Zero: 2890

Polynomial Gage Factors: A: 1.2568E-07 B: 0.04198 C:                     

Calculate C by setting D = 0 and  $R_1$  = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001708 (inches/digit)

Polynomial Gage Factors: A: 4.9482E-09 B: 0.001653 C:                     

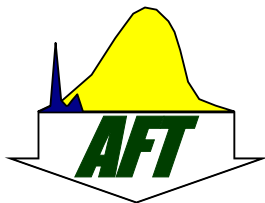
Calculate C by setting D = 0 and  $R_1$  = initial field zero reading into the polynomial equation

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

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

Refer to manual for temperature correction information.

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.  
This report shall not be reproduced except in full without written permission of Geokon Inc.



## **Appendix D**

### **Analysis Method Supplement**

#### **Report of Bi-Directional Load Testing – Test Shaft**

Rainy River Bridge  
Baudette, Minnesota

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## Guide to Calculations and Analysis

Applied Foundation Testing, Inc.

4035 J. Louis Street

Green Cove Springs, FL 32043

P: (904) 284-1337 F: (904) 284-1339

E: [info@testpile.com](mailto:info@testpile.com)

[www.testpile.com](http://www.testpile.com)

Version	Authored	Approved	Release Date
1.1	JDN	MKM	12/3/2015





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## Introduction

This document is provided to describe the methodology by which results are obtained from an AFT-Cell® Bi-Directional Load Test. The AFT-Cell® is a proprietary test method that nevertheless conforms to industry-recognized approaches to geotechnical load testing and instrumentation to produce accurate, reliable results. Note that the AFT-Cell test method is in conformance with the soon to be released ASTM standard on Bi-Directional Static Load Testing.

In some cases, this document may be provided in support of a finalized report or as part of a submittal package. It is intended as a general explanation of the methodology used and not an exhaustive or specific guide to any individual test(s). Furthermore, for tests conducted in accordance with a third-party published test method, for any potential conflict between this document and the cited test method the cited test method is to take precedence.

For clarification or additional information, please contact Applied Foundation Testing.



### Applied Foundation Testing, Inc.

4035 J. Louis Street

Green Cove Springs, FL 32043

P: (904) 284-1337 (office direct)

E: [drobotson@testpile.com](mailto:drobotson@testpile.com) (Don Robertson)

[www.testpile.com](http://www.testpile.com)

OR

### Applied Foundation Testing, Inc.

2345 Success Drive

Odessa, FL 33556

P: (727) 376-5040 (office direct)

E: [mmuchard@testpile.com](mailto:mmuchard@testpile.com) (Mike Muchard)



## Test Setup

### Bi-Directional Jacks

For a given AFT-Cell test, one or more groups of one or more AFT-Cell embedded bi-directional jacks are installed in the reinforcement cage prior to installation in the foundation. The jack groups are installed at predetermined elevations commonly referred to as **cell levels** and are plumbed in a manifold arrangement to maintain equivalent pressure amongst all cells at each level. Provided all AFT-Cells at a given level share a common calibration (equivalent area) and are located equidistant from the shaft centerline, fluid statics in this arrangement guarantees that the load distribution will be centralized. Eccentric loading identified in neighboring strain gage levels will therefore be caused by other factors such as the geometry of the shaft and not by any inherent flaw in the test arrangement.

Each cell level is instrumented for pressure measurement at the surface at the supply pump. The cell level is also instrumented for expansion displacement using embedded displacement transducers and/or telltale rods.

An important concept for AFT-Cell testing—and indeed any bi-directional load testing—is that the load is reacted equally above and below the cell level into the shaft such that a reasonable balance of resistance is obtained. The AFT-Cell placement is therefore very important and requires input from the geotechnical engineer of record. Another concept is that the bi-directional loading stress is half that of a top down applied force from an anchored reaction frame or kentledge type top-down load test. In many cases, it may be desired to use the bi-directional results to estimate a would-be top down response of the foundation under test. This requires calculation of an **equivalent top load curve**, discussed in the following sections, which considers the additional stress imposed to the foundation in a top loading scenario.

### Displacement Instruments

In addition to the embedded displacement transducer(s) used for cell opening (expansion) displacement, AFT-Cell tests are also commonly conducted with direct measurement of **segmental displacement** and **segmental compression** using cased rods commonly known as **Telltale**s and reusable displacement transducers located above the surface. Depending on the test arrangement, Telltales may pass through or terminate above cell levels.

**Top of shaft (TOS) displacement** is measured directly using digital survey technology. Depending on the test arrangement, multiple digital surveys may be used for redundant measurements or to maintain measurement with respect to a fixed reference point commonly known as a **Backsight**. A traditional **reference beam** has been made obsolete with the advent of digital survey technology. Reference beams, which have always been susceptible to environmental side effects, are therefore not used.

### Strain Instruments

Strain transducers in an AFT-Cell test are typically embedded instrumented rebar sections commonly known as **sister bars**. Sister Bars may be based on resistive foil or vibrating wire technology. Resistive gages are more economical, and as reliable as VW gages. Strain transducers are installed in the rebar cage prior to installation at predetermined elevations referred to as **strain levels**. Each strain level contains multiple strain transducers placed with even numbers of gauges per any given level depending on the test arrangement. Generally, **shaft segments** are bounded by strain levels and cell levels



## Time Domain Calculations

The first step in conducting analysis of AFT-Cell test data is to calculate certain useful data in the time domain. Depending on the software application many of these calculations are typically done in real time during the test.

### Segmental Displacements

For each Cell Level  $i$  the **cell level expansion** is defined in Equation 1.1

$$\Delta_{Cell,i} = \overline{\Delta_{Cell,i,j}} \quad (1.1)$$

Where  $\Delta_{Cell,i,j}$  is the individual reading of each cell opening displacement sensor at Cell Level  $i$ .

**Segmental compression** values for a given individual shaft Segment  $N$  may be determined from one or more instrumented Telltales (Equation 1.2) or alternatively from the average strain in the segment integrated over the section length (Equation 1.3).

$$\Delta_{Comp,n} = \Delta_{TTC,n} - \sum_{k=1}^{n-1} \Delta_{Comp,k} \quad (1.2)$$

$$\Delta_{Comp,n} = \int \varepsilon dL_n \quad (1.3)$$

Equation 1.3 assumes the strain distribution is uniform over the section length.

**Segmental displacement** values for a given individual shaft Segment  $N$  may then be determined using Equation 1.4 and the results from Equations 1.1, 1.2, and 1.3 or alternatively may be calculated from one or more instrumented Telltales (Equation 1.5).

$$d_n = \Delta_{Cell,n} - \Delta_{Comp,n} - d_{n-1} \quad (1.4)$$

$$d_n = \Delta_{TTd,N} - d_{n-1} \quad (1.5)$$

Note that in the previous equations, a special case arises for  $d_0$  which is the **top of shaft displacement**. For this segment, we assume zero length and therefore zero compression.  $d_0$  is then calculated from digital survey values as shown in Equation 1.6.

$$d_0 = \overline{\Delta_{TOS}} - \Delta_{Backsight} \quad (1.6)$$

### Cell Level Displacements

The **Top of Cell (TOC) displacement** for a given AFT-Cell level  $i$  is calculated as the measured top of shaft displacement plus the elastic compression for the portion of shaft above the AFT-Cell as shown in Equation 1.7 for the case of using segmental compression values. Equation 1.8 is for the case of using direct measurement of elastic compression via Compression Telltale.

$$\Delta_{TOC,i} = d_0 + \sum_{k=1}^i \Delta_{Comp,k} \quad (1.7)$$

$$\Delta_{TOC,i} = d_0 + \Delta_{TTC,i} \quad (1.8)$$



The **Bottom of Cell (BOC) displacement** at the AFT-Cell is obtained using Equation 1.9 and readings from multiple instruments: with embedded cell displacement transducers (where applicable), expansion telltales, or both. The basic calculation is the same in all instances and is simply the total cell expansion less the top of cell expansion determined in Equation 1.7 or 1.8.

$$\Delta_{BOC,i} = \Delta_{Cell,i} - \Delta_{TOC,i} \quad (1.9)$$

The cell level displacement is then plotted versus the cell level gross load to obtain the plot shown in Figure 1. Note that an independent plot can be generated for any given cell level.

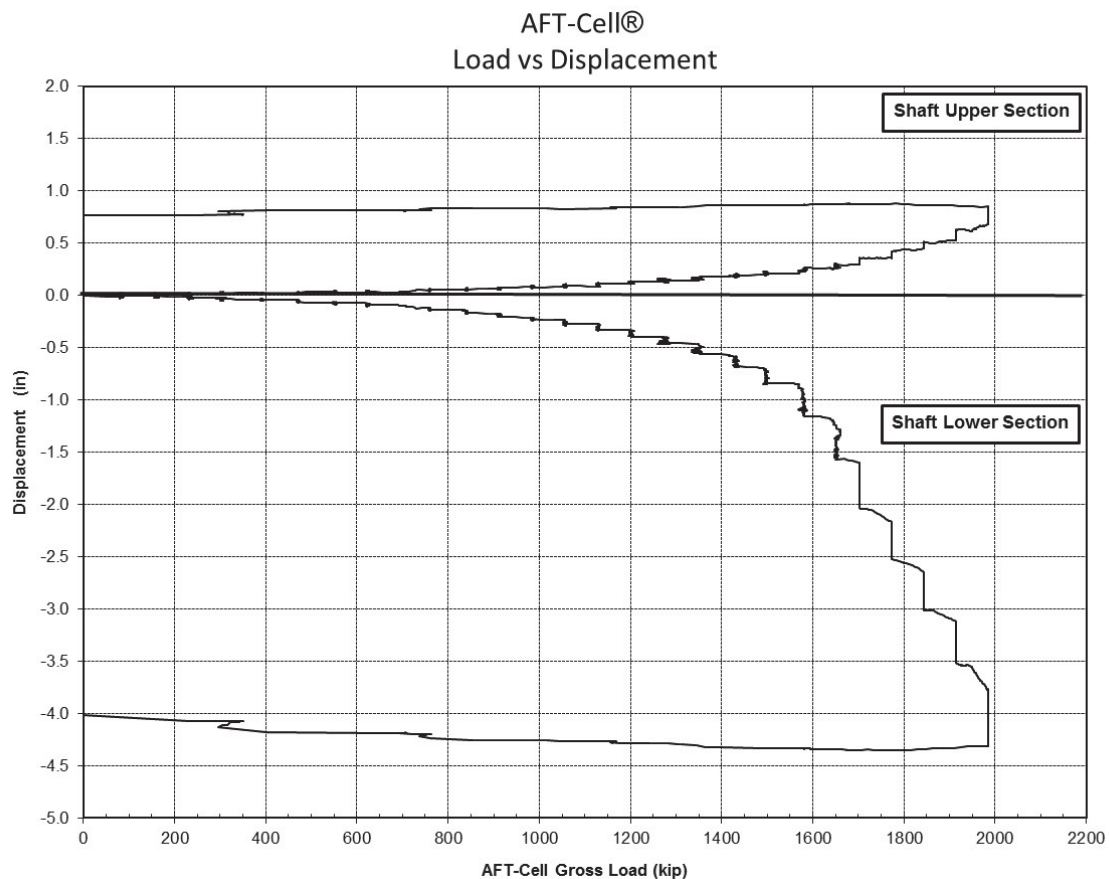


Figure 1: AFT-Cell® Load vs Displacement diagram. Continuous data acquisition.



## Segmental Elasticity

For each Strain Level  $i$ , Equations 1.10, 1.11, and 1.12 are applied

$$\varepsilon_i = \overline{\varepsilon_{i,j}} \quad (1.10)$$

$$\sigma_i = E_i \varepsilon_i \quad (1.11)$$

$$F_i = A_i E_i \varepsilon_i \quad (1.12)$$

Where  $E_i$  is the **composite modulus** and  $A_i$  is the **effective cross sectional area** at Level  $i$ .

AFT often uses **Thermal Integrity Profiling (TIP)** for shaft shape profiling to aid in determination of  $A_i$ . AFT may use other shape profiling methods such as mechanical or acoustic calipering (**SoniCaliper™**) if requested by the client, however TIP is the method preferred by AFT due to its ability to address a number of shortcomings in calipering methods.

**Borehole calipering** adds considerable effort and time during the shaft construction at a time sensitive portion of the construction process: when the shaft excavation is open. The wire method of TIP (ASTM D7949 Method B) minimally impacts the construction timeline and does so during reinforcement cage construction, which is a far less time sensitive phase in drilled shaft construction.

Borehole calipering is also limited in that it measures the shaft dimensions prior to concrete placement. These dimensions have the potential to change between calipering and completion of construction (e.g. sloughing, bulging of weak zones due to concrete forces, etc.). TIP provides an as-built shaft shape profile which enhances the accuracy of the calculation of  $A_i$ .

For each Cell Level  $i$ , load is calculated from the calibration of the AFT-Cell(s) and the recorded pressure as shown in Equation 1.13 and used as a boundary value for adjacent segments.

$$F_{Cell,i} = 2 * \sum_{j=1}^k C_{i,j} P_i \quad (1.13)$$

Note the nominal force is doubled in order to represent the bi-directional nature of the applied force assuming that the length of Cell Level  $i$  is negligible. Each AFT-Cell is calibrated in-house with NIST traceable equipment.



## Load Distribution

With the given calculations performed, a load distribution plot may now be generated as shown in Figure 2. For each load increment, the level force  $F_i$  is presented as a function of elevation. The resulting composite plot provides information about load shedding and the geotechnical nature of foundation under test.

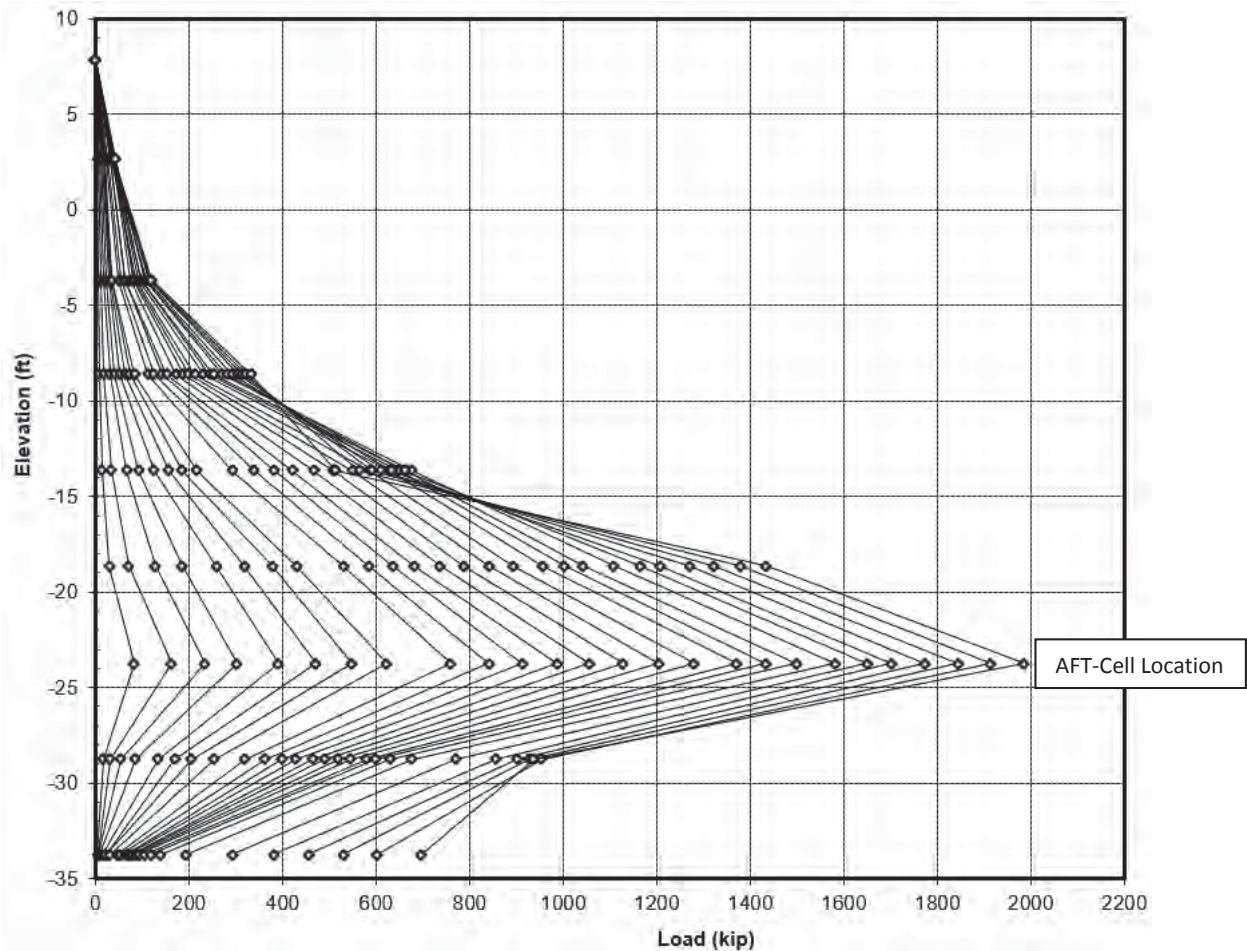


Figure 2: AFT-Cell® Load Distribution plot





## Unit Side Shear

### Side Shear Calculation

For each shaft Segment  $n$ , the **unit side shear**  $\tau_z$  may be calculated from the load shed across the segment and the surface area of the segment. Note that Equation 2.1 is a general form; load directionality and **buoyant forces** change across cell level boundaries.

$$\tau_{z,n} = \frac{(F_{i+1} - F_i) - F_{Buoyant,n}}{A_{S,n}} \quad (2.1)$$

The buoyant force is taken as the equivalent force due to the submerged (below water table) self-weight of the shaft above the segment under investigation. To be consistent with current analysis practice, the load acting upward is assumed to be zero until the buoyant weight of the shaft above is overcome. Therefore, the *net load* is the *gross load* minus the buoyant weight of the shaft above the AFT-Cell.

### Tz Plot

Following calculation of  $\tau_{z,n}$  in the time domain, a  $\tau_z$  plot is produced by plotting segmental displacement  $d_n$  as a function of  $\tau_{z,n}$ . Multiple plots are usually produced to maintain a cohesive representation of displacement directionality across cell level boundaries as shown in Figures 3 and 4.

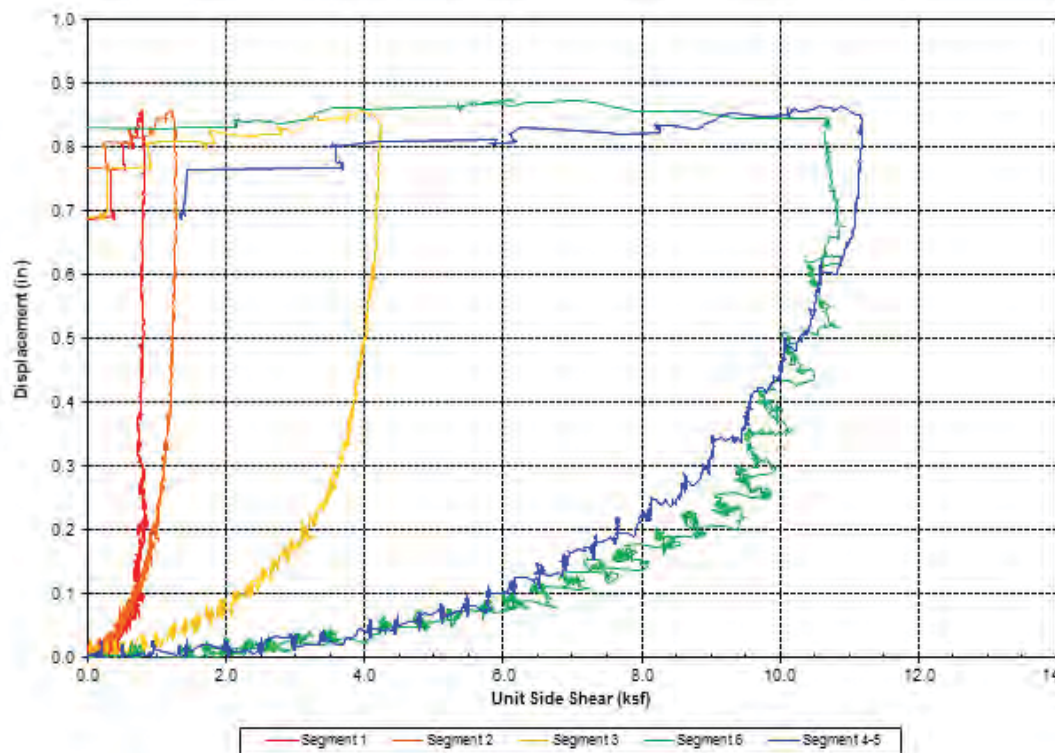


Figure 3: Example of a Tz plot with upward segmental displacements. Continuous data acquisition.



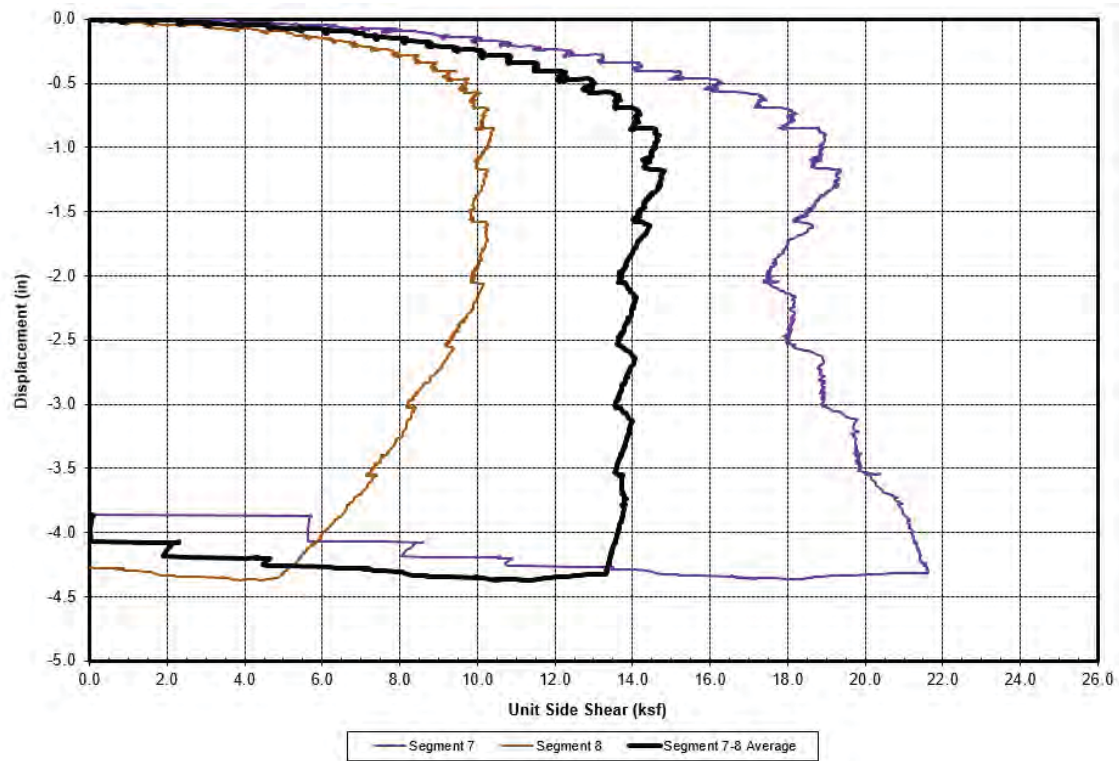


Figure 4: Example of Tz plot with downward segmental displacements. Continuous data acquisition.



## End Bearing

### End Bearing Calculation

For the lowest shaft Segment  $N$ , **end bearing**  $q_z$  may be calculated from the portion of the segmental force reacted through the tip divided by the area of the tip. The key assumption for this calculation is that the unit side shear for Segment  $N$  is equal to the unit side shear for Segment  $N - 1$ , thereby allowing the portions of the segmental force reacted through shear and end bearing to be decoupled as shown in Equation 3.1.

$$q_z = \frac{F_N - (A_{S,N} * \tau_{z,N-1})}{A_{C,N}} \quad (3.1)$$

### Qz Plot

Following calculation of  $q_z$  in the time domain, a  $q_z$  plot is produced by plotting the displacement  $d_N$  as a function of  $q_z$  as shown in Figure 5.

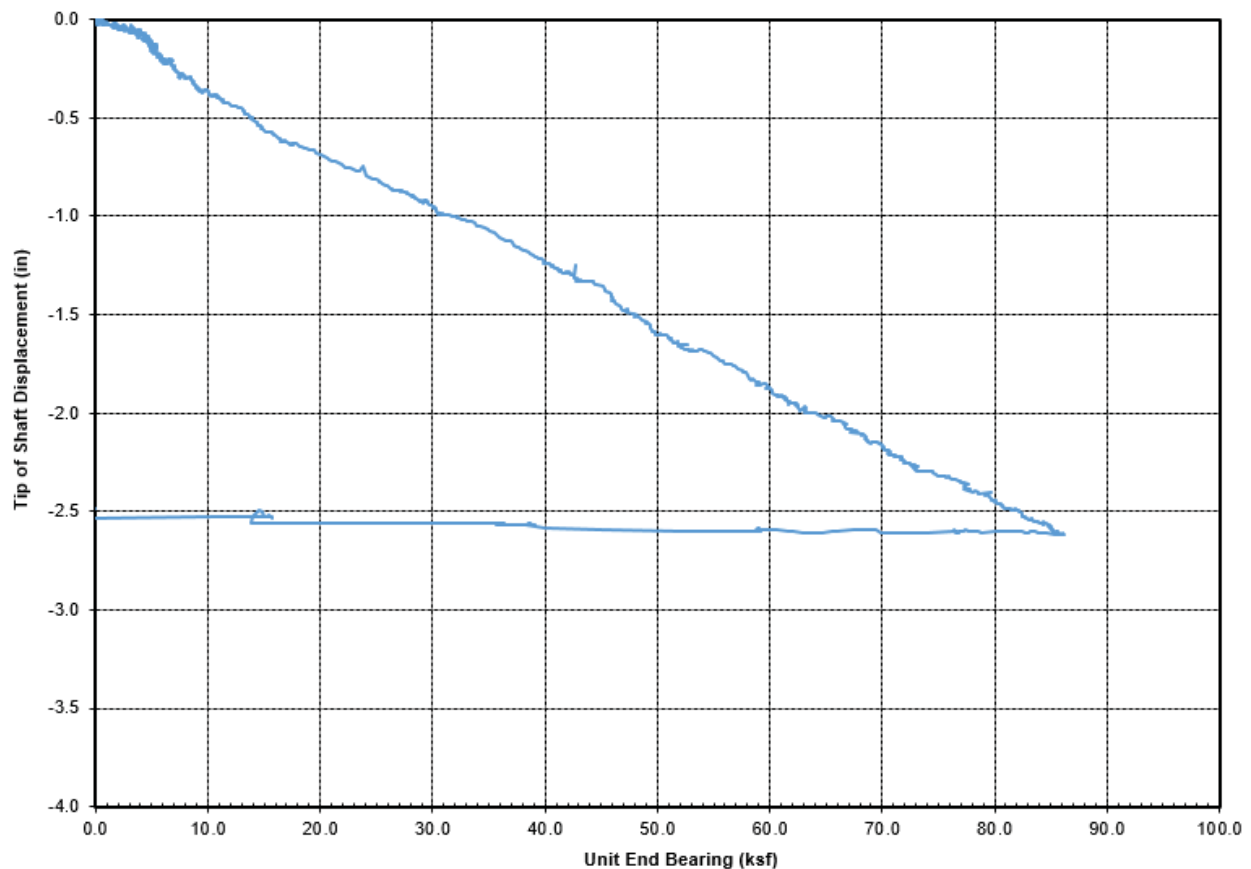


Figure 5: Example  $q_z$  plot

## Equivalent Top Load

The Equivalent Shaft Top Load vs Displacement plot is produced in order to model the shaft behavior as if it had undergone a traditional top-down static load test. Conceptually, the plot is a representation of the average load-displacement behavior of the shaft Segments between cell level and top-of-shaft and bottom-of-shaft boundaries. Each of these segmental groups can be conceived as a separate load test with their aggregate representing the overall performance of the shaft. For each Cell Level  $i$ , at each discrete load stabilized time interval  $t$ , Equation 4.1 is used to develop the Equivalent Top Load.

$$F_{Eq,i,t} = F_i(d_{i,UPPER}(t)) + F_i(d_{i,LOWER}(t)) \quad (4.1)$$

The equivalent top of shaft displacement for this plot is defined in the time domain according to Equation 4.2.

$$d_{0,EQ,i} = -d_{i,UPPER}(t) \quad (4.2)$$

A more precise calculation for equivalent top of shaft displacement accounts for additional elastic compression in the shaft at the given equivalent top of shaft load as shown in Equation 4.3.

$$d_{0,EQ,Corrected,i} = -\left[d_{i,UPPER}(t) + \sum_{k=1}^N \Delta_{Comp,k}\left(\frac{F_{Eq,i,t}}{2}\right)\right] \quad (4.3)$$

The resultant data is plotted in the Equivalent Top Load domain as shown in Figure 6.

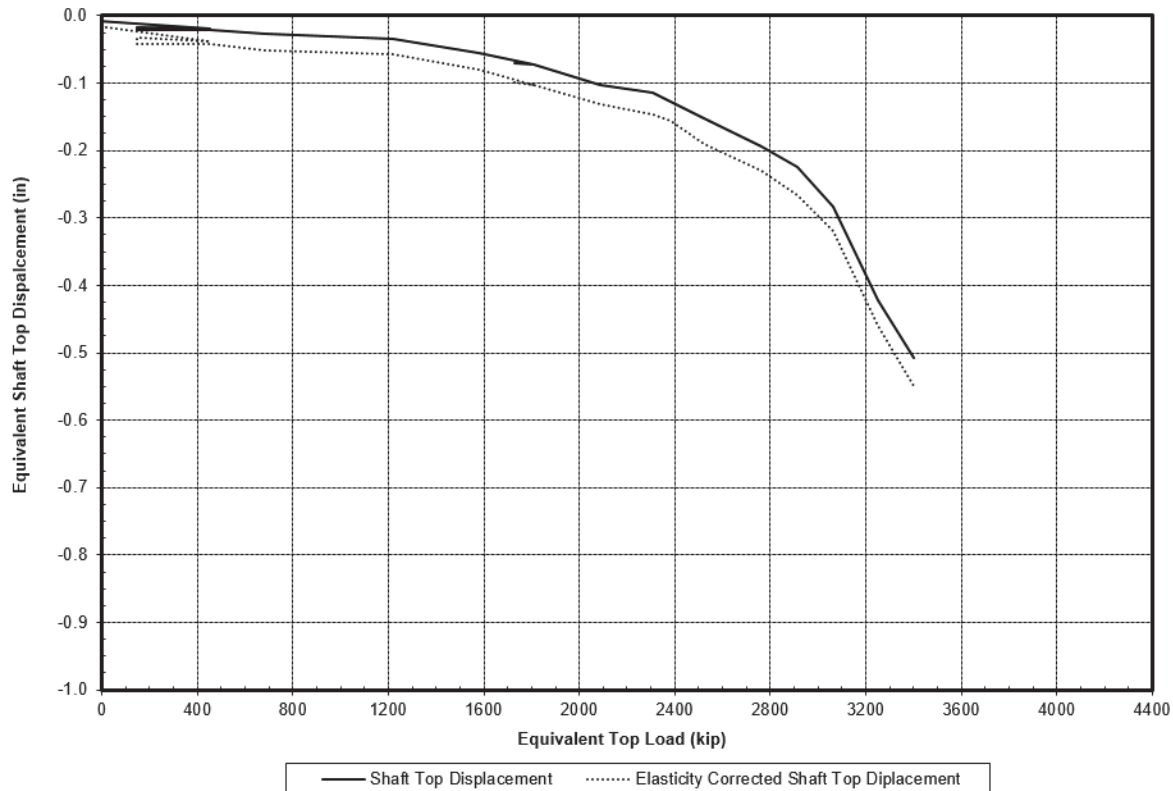


Figure 6: Example Equivalent Top Load vs. Displacement Plot with and without elasticity correction



## Creep Limit

AFT-Cell tests can provide an evaluation for an equivalent top load on the foundation under investigation that could potentially create excessive creep behavior. This load value is frequently referred to as the **creep limit** or **yield limit**. AFT applies the methodology proposed by Housel (1959) to the AFT-Cell test by calculating individual values for creep for segmental groups surrounding the cell levels.

Creep is calculated for each group of shaft segments above and below each Cell Level  $i$  during each discrete load stabilized time interval  $t$  as shown in Equation 5.1. Generally the data for each segmental group is presented as upper section and lower section creep data, however for multiple cell levels this leads to redundancy and a numbering scheme may be employed.

$$\delta_i = d_i(t_2) - d_i(t_1) \quad (5.1)$$

The creep limit plot is produced by plotting creep  $\delta_i$  as a function of gross load as shown in Figure 7. The creep limit is then judged as the gross load at which significant creep is observed and is indicated by a linear fit. The final value reported for creep limit depends on the nature of the result

Case 1: For two distinct values of  $\delta_i$  obtained at Cell Level  $i$ , the creep limit is defined by the load at which free motion of *both* segmental groups would be observed. Therefore, the greater of the two values is reported.

Case 2: For a case in which one value of  $\delta_i$  is determined but the other segmental group does not exhibit creep behavior before reach maximum displacement, the creep limit is reported to be unknown, but greater than the maximum load applied to the segmental group that did not exhibit creep behavior.

Case 3: For a case in which  $\delta_i$  cannot be determined for either segmental group, the creep limit is reported to be unknown, but greater than the maximum equivalent top load.

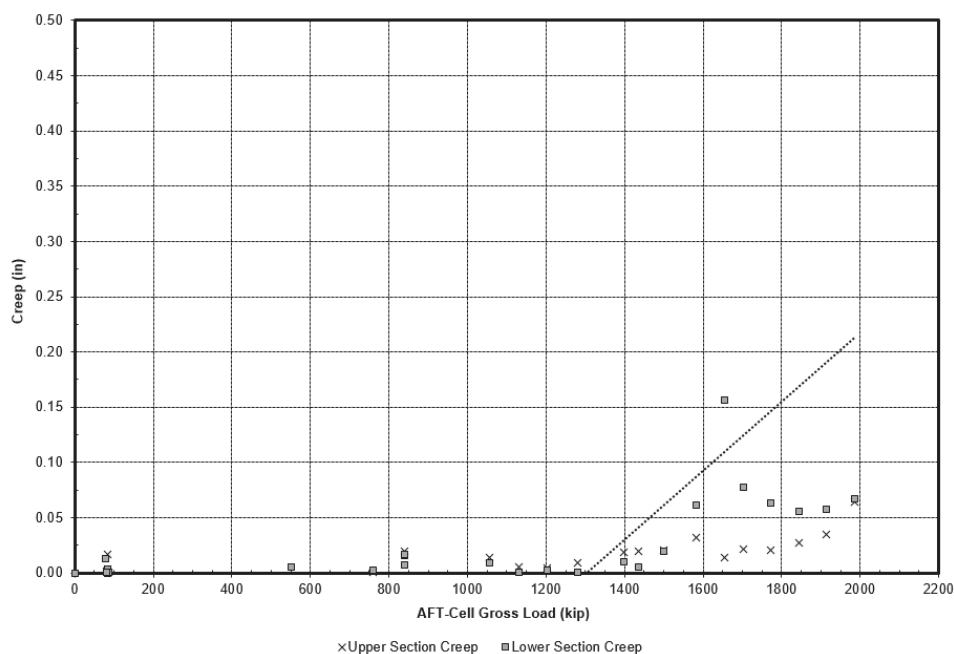


Figure 7: Example Creep Limit plot



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