ERI-60-3.100 Bridge in Erie County, Ohio
Part I: Drilled Shafts for Slope Stabilization and Bridge Support

April 10, 2019

Presentation at

10th Geo^{3}T^2 Conference

Session 5A-1

Jamal Nusairat, Ph.D., P.E.

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Overview

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July 2001, a new structure was designed

Contractors Input in Design

- Design Consultant-Richland Engineering Limited, Mansfield, OH
- General Contractor-S.E. Johnson Companies, Inc., Maumee, OH
- Geotechnical Consultant-BBC&M Inc, Dublin, OH
- Drilled Shafts-Millgard Corp., Livonia, MI
- Rock Anchors-Schnabel Engineering, Chicago, IL
- Instrumentation and Monitoring- E.L. Robinson, Columbus, OH

Subsurface Investigation and Field Observations

- A total of 34 soil borings were performed over multiple phases for this project by BBCM
- Installation of 5 inclinometers and monitoring
- Slope stability analyses
- Evidence of slope movement
  - Cracking at surface - Measured crack widths
- Sloping bedding planes in bedrock at exposure on north side of river within upper bedrock unit

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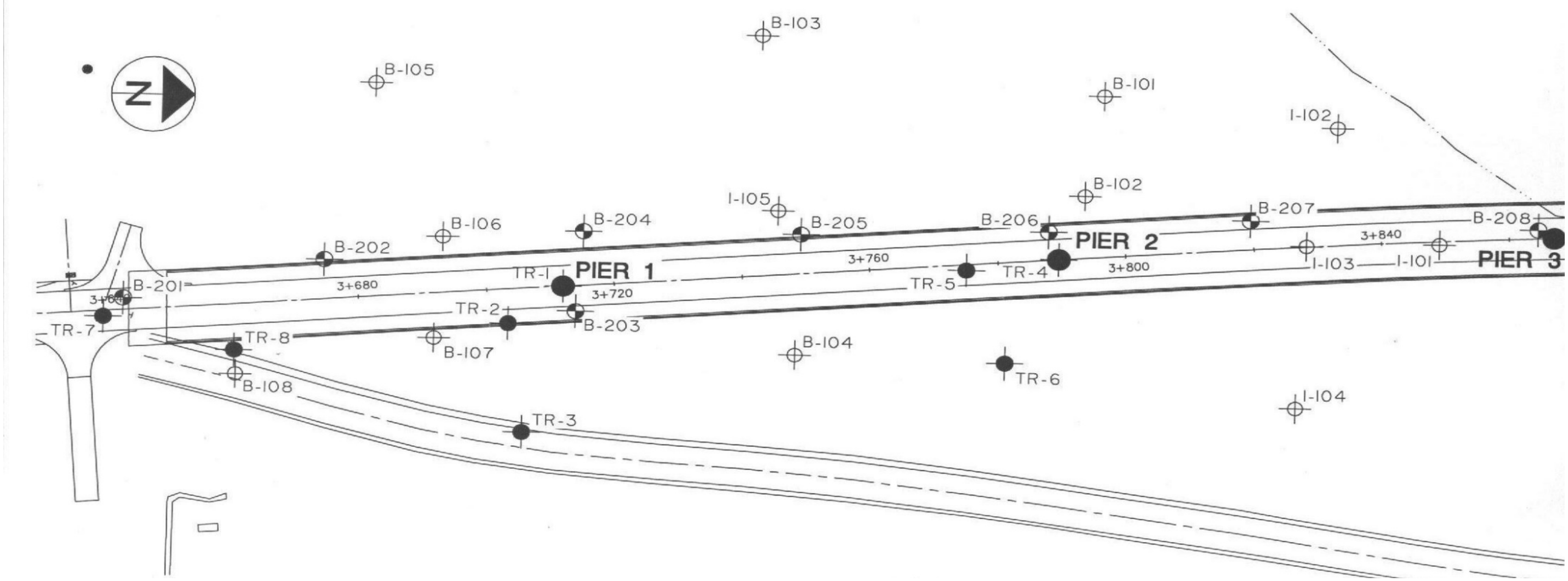
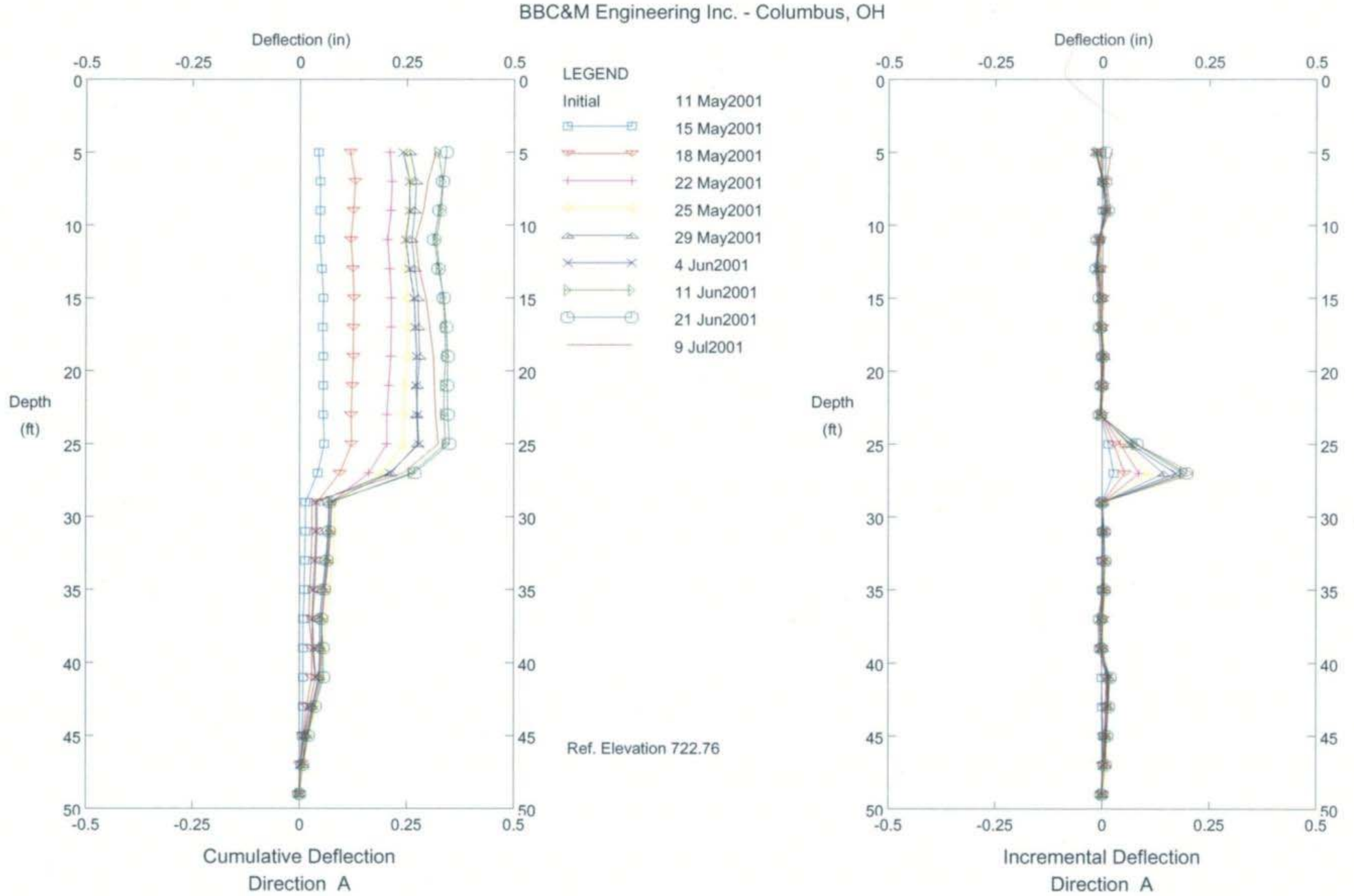

N
B-103
B-105
B-101
I-102
B-102
I-105
B-106
B-204
B-205
B-206
PIER 2
B-207
B-208
B-202
PIER 1
3+760
3+840
PIER 3
B-201
3+680
TR-1
3+720
TR-5
TR-4
3+800
I-103
I-101
3+640
TR-2
B-203
TR-7
TR-8
B-107
B-104
TR-6
B-108
I-104
TR-3



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Soil Borings and Inclinometers

- Several distinct layers of bedrock were encountered within all of the borings
- Inclinometers indicated significant movement near the interface of the reddish brown Bedford Shale and the gray becoming dark gray Ohio Shale
- Direct shear testing—residual strength
- Residual Friction Angle for Design = 10^{o}

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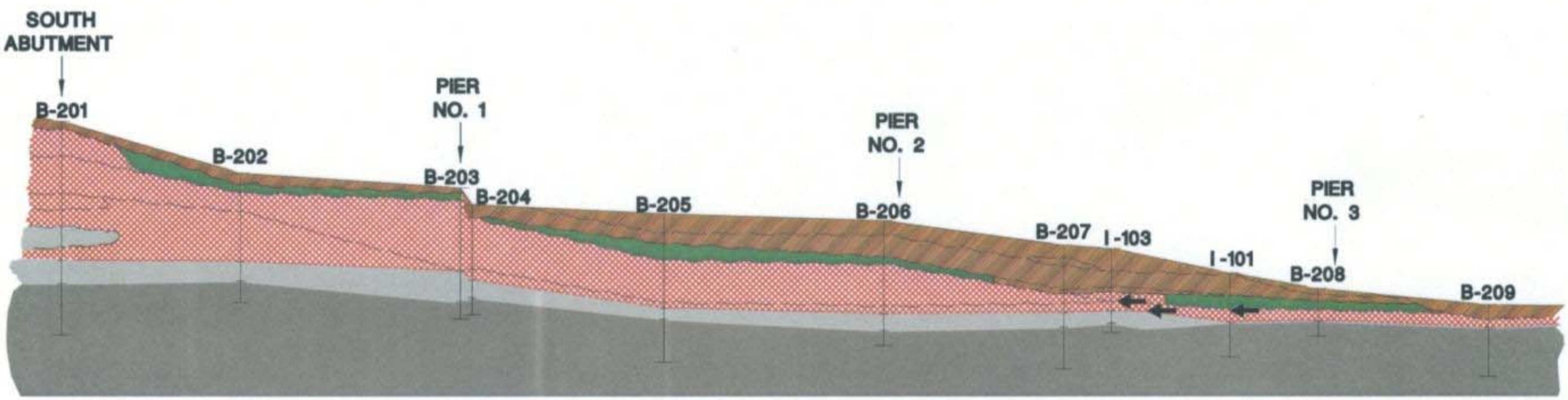

FILL OR SILTY CLAY SOIL

BROWN SHALE SIMILAR TO SOIL

VERY-SOFT RED-BROWN SHALE SIMILAR TO HARD CLAY

SOFT TO MEDIUM-HARD GRAY SHALE

MEDIUM-HARD DARK-GRAY SHALE

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Slope Stability Analyses

- The intention was to determine if deep failure surface was possible or if likely only shallow
- Provided an indication of the relative factors of safety for various failure surfaces
- Considered residual strength of shale

Conclusions of Subsurface Investigation

- Instability appeared to be in upper bedrock layer known as Bedford Shale
- Foundations on the slope would either need to resist applied earth loading or else would need to stabilize entire slope
- Several general options were discussed to allow for construction of the bridge

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Proposed Structure

- The decision was made to utilize a relatively long structure spanning the entire valley supported by 4 high capacity piers
- The piers would be supported on drilled shafts designed to carry any applied earth load with tolerable deflection at the top

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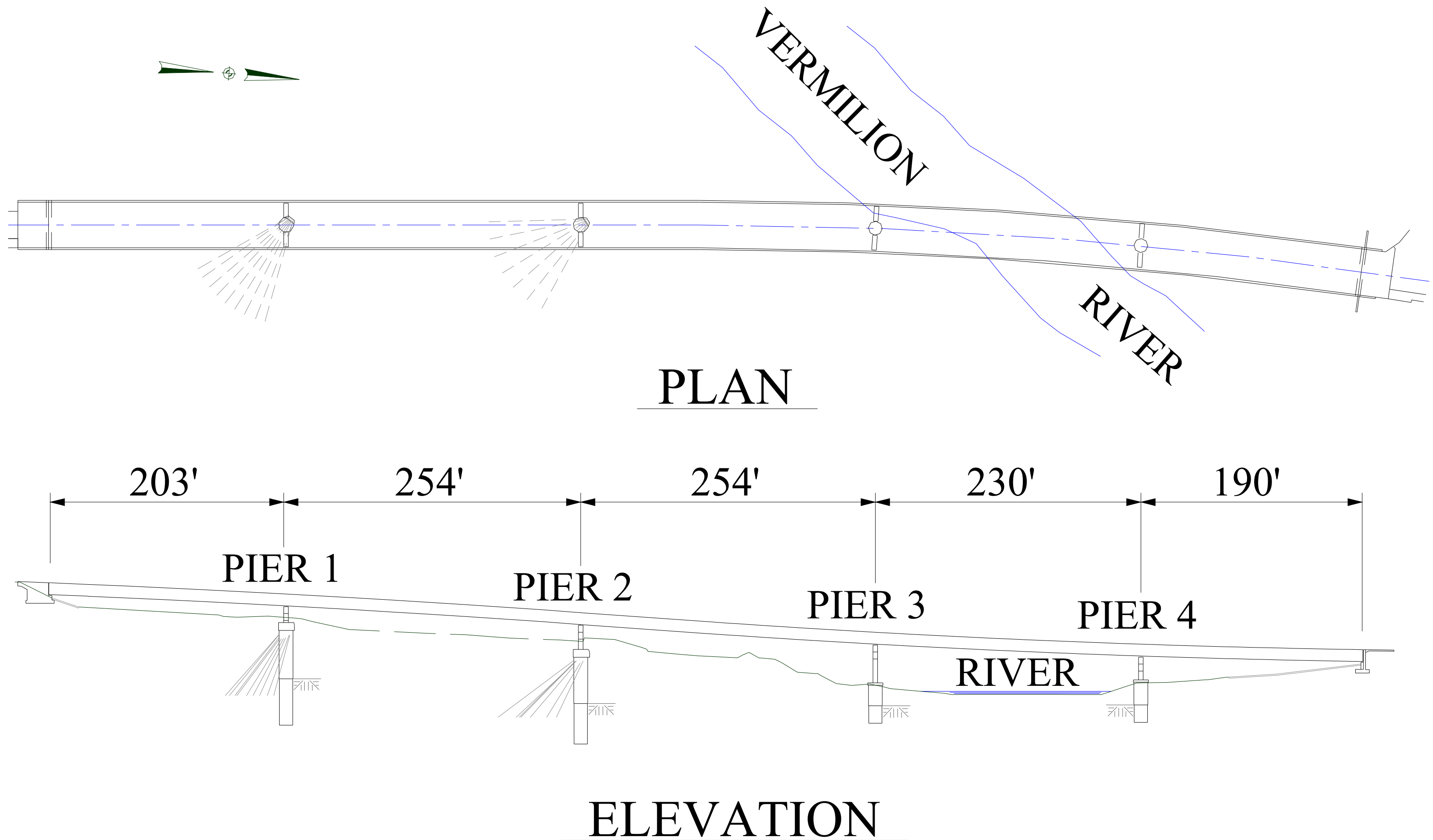

S.R. 60 Over Vermilion River

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Determination of Shaft Load

- Intent was to have shafts resist applied soil loads which would likely occur over time; not to stabilize the entire slope
- Based on presence of slickensides, inclinometer data, and shear strength, change from loading to resistance taken as the interface of Bedford and Ohio Shale

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Long Term Shaft Loading Caused by Moving Earth

- Magnitude based on at rest condition, insufficient movement to consider active
- Residual shear strength of shale used for computations
- Zone of influence taken into account by computing load over 3 shaft diameters

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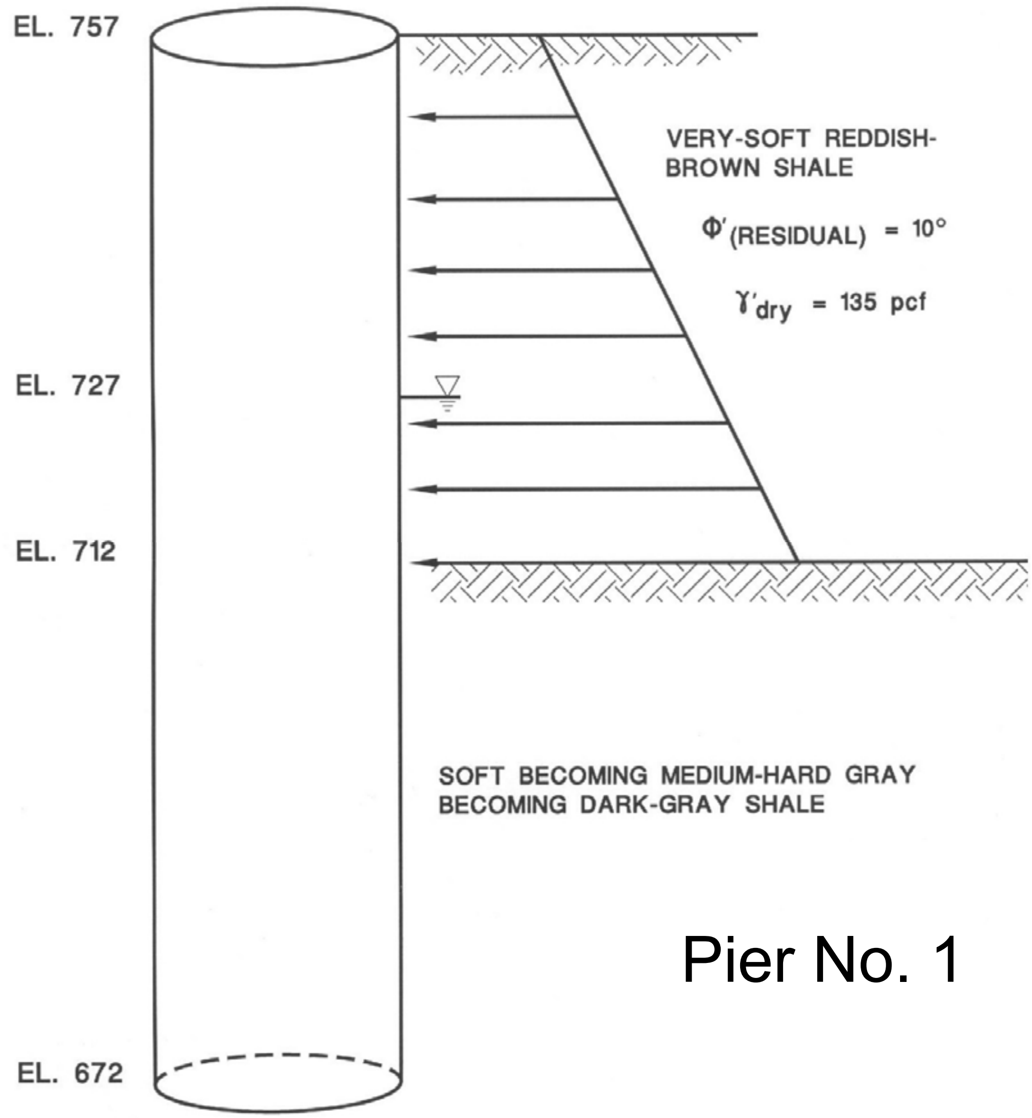

EL. 757
EL. 727
EL. 712
EL. 672
VERY-SOFT REDDISH-
BROWN SHALE
Φ′(RESIDUAL) = 10°
γ′dry = 135 pcf
SOFT BECOMING MEDIUM-HARD GRAY
BECOMING DARK-GRAY SHALE

Pier No. 1

Design of Shafts

- Iterative procedure using the computer program LPILE
- Stiffness of the shaft for geotechnical models considered all reinforcement
- Analyzed two general conditions

  1) Long term with earth loading shafts

  2) Short term with shafts loading earth

Structure Design

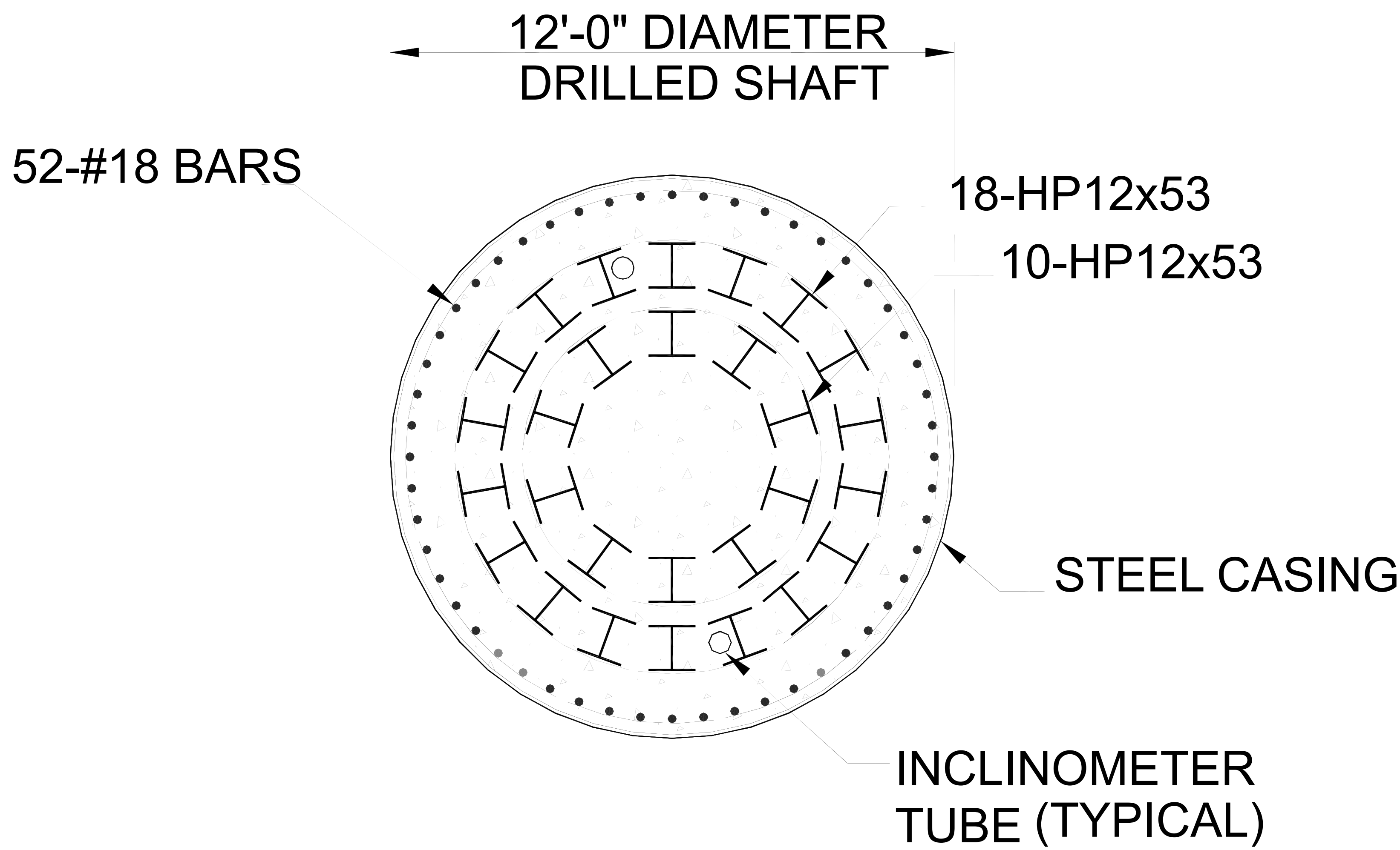
- Vertical cantilevered beam with lateral load
- Column with vertical eccentric loading
- Rock socket for fixity
- Analyzed as a reinforced concrete column with vertical and lateral loading

12’ Diameter Drilled Shafts

- Single shaft to minimize applied load
- High strength 5 ksi concrete to minimize shaft diameter
- Larger diameter resists more load, requires more reinforcing
- Smaller diameter does not have enough space for reinforcing

Shear Resistance in Shaft

- Shear load determined shaft diameter
- 12’ diameter required to contain enough reinforcing steel for shear resistance
- H piles used for shear reinforcement
- H piles small in size in proportion to concrete area



Section Through Drilled Shaft Rock Socket

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Refine Foundation Design

- Rock anchor tiebacks to reduce bending moment and deflection
- Reduce ground elevation to reduce load and lower tieback connection point
- Contractor input in design

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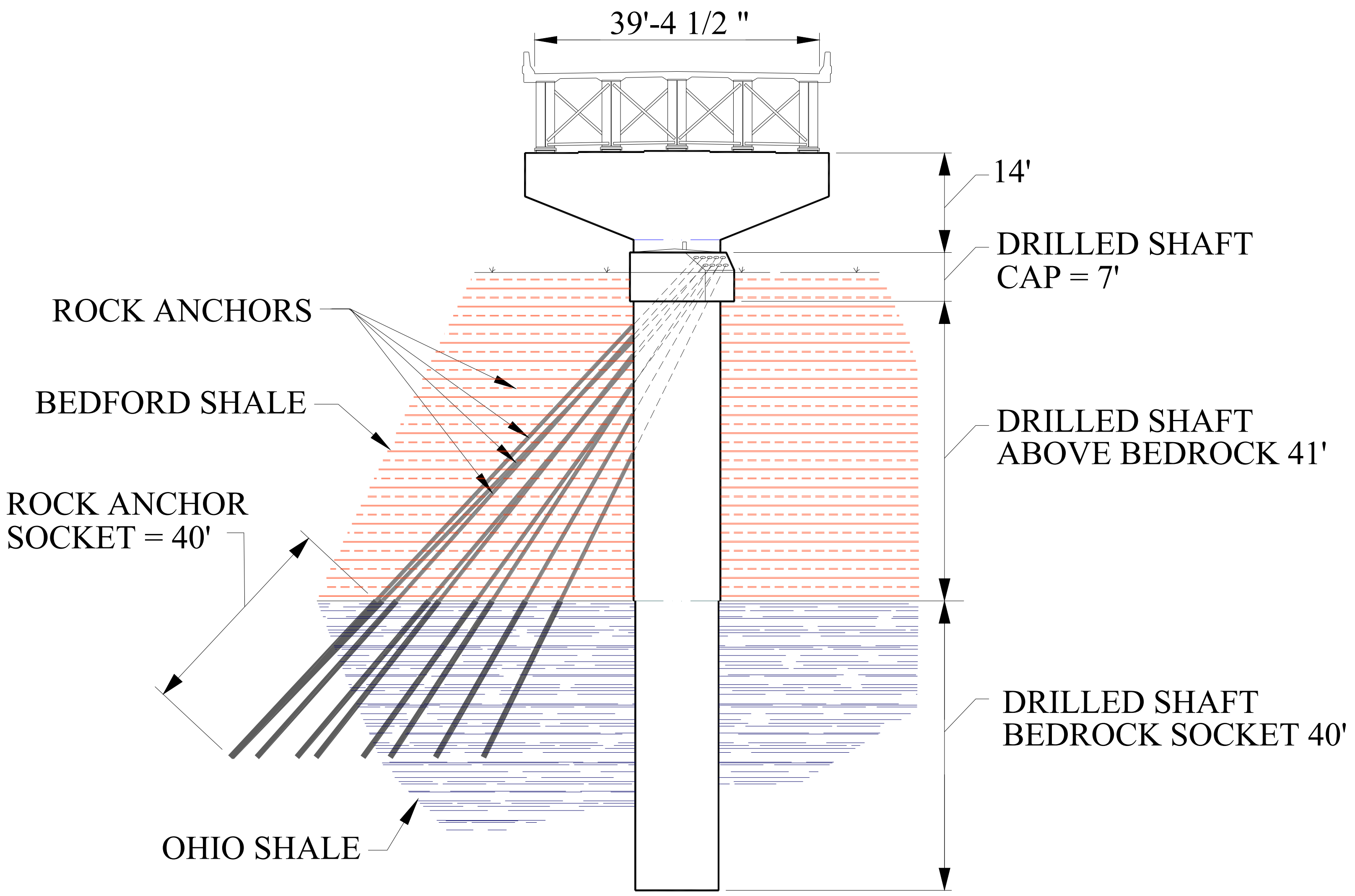

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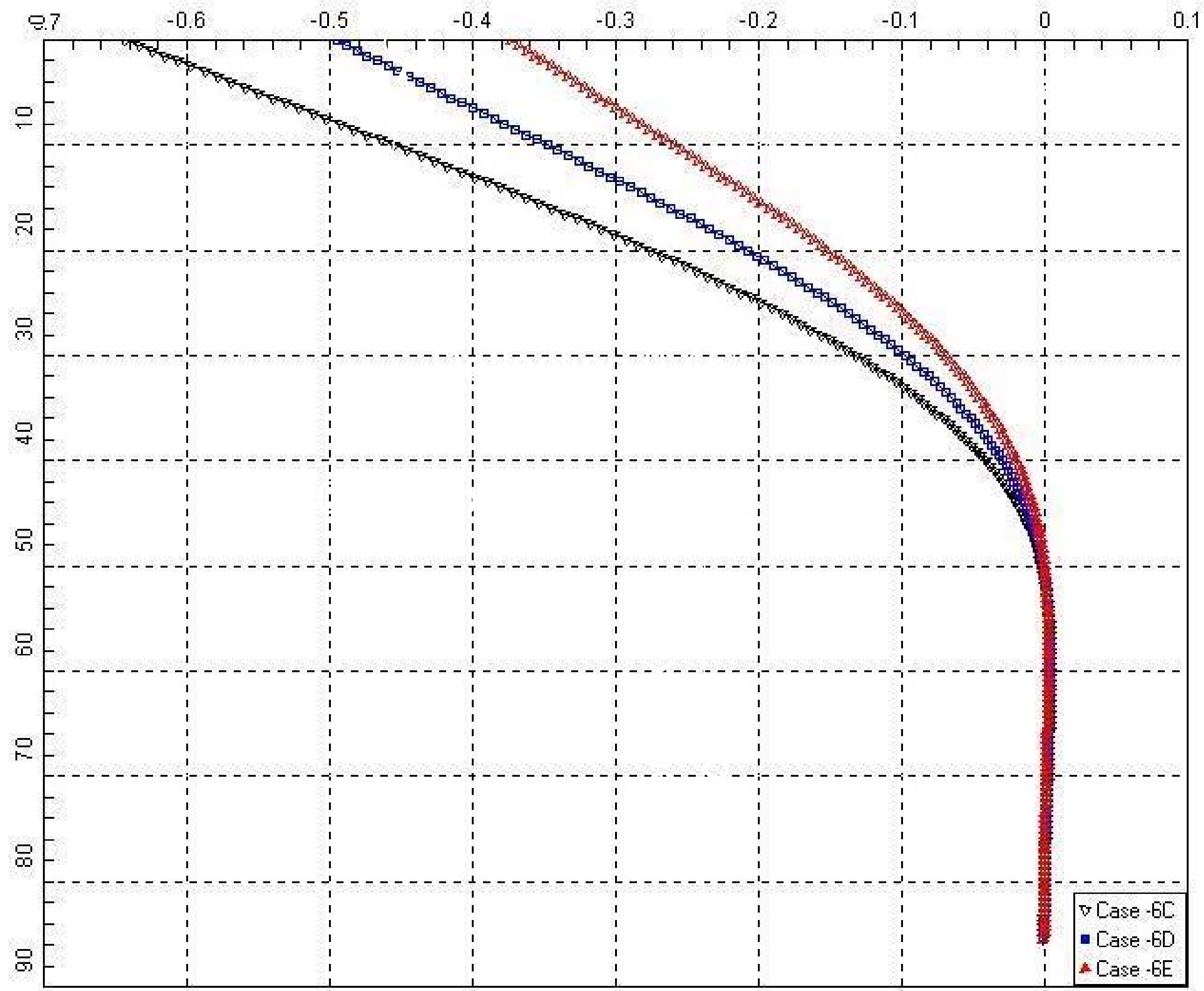
ier 1 Elevation

Pier 1, Trial 6 – Strong Rock Model – Passive Load Case



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Rock Anchors

- 45 degree angle from vertical to stay within right of way
- Multiple anchors for redundancy and to limit size (14 strand, 490 kips/each)
- Fanned to allow for variation in direction of applied load
- Redundant corrosion protection

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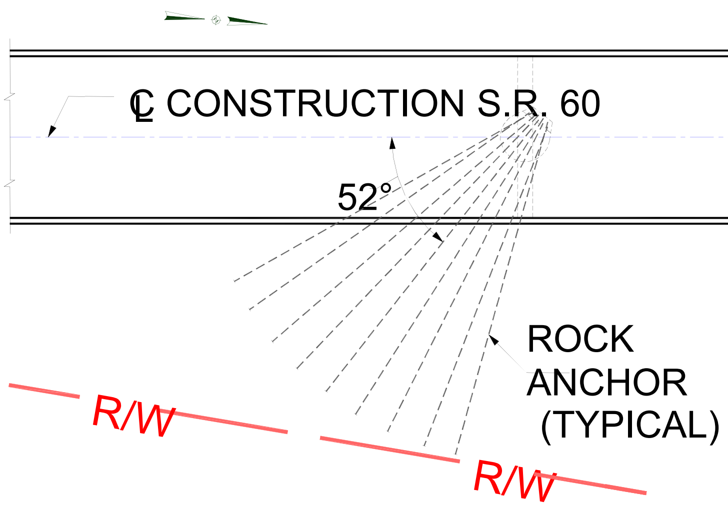
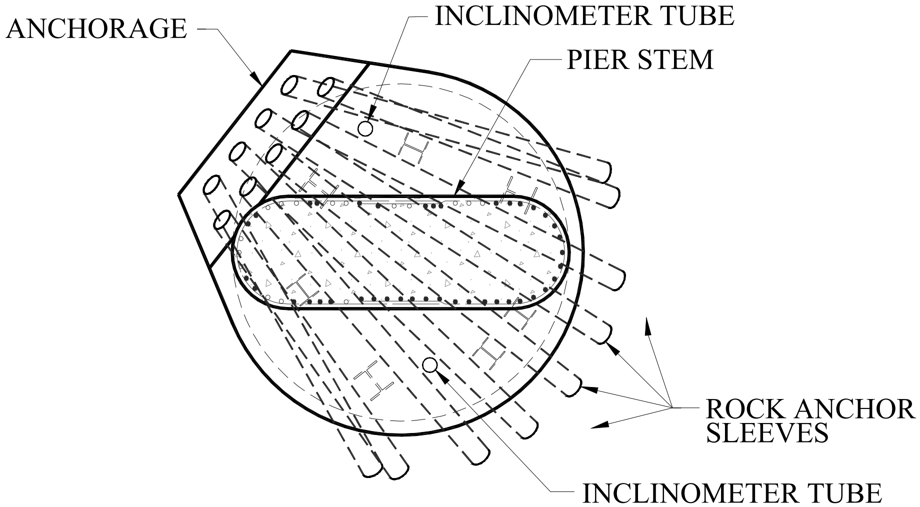


Pier 1 Plan



Section Through Drilled Shaft Cap

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Construction Methods

- Auger drilled through Bedford shale in one day, 12’-6” diameter (40’ deep)
- Steel casing installed above bedrock, 12’-0” diameter
- Core barrel drilled through hard shale in 5 days, 11’-6” diameter (40’ deep)

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ERI-60-3.100 Bridge in Erie County, Ohio
Part II: Instrumentation and Long-term Monitoring

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Objectives

- Plan and execute instrumentation and monitor load testing of Piers 1 and 2.
- Study the temperature effect on massive pours
- Determine the soil and bedrock p-y curves.
- Determine load-deformation characteristics of the drilled shaft.
- Measure the actual lock off load in the anchors.
- Monitor the Piers and the slope during service life.

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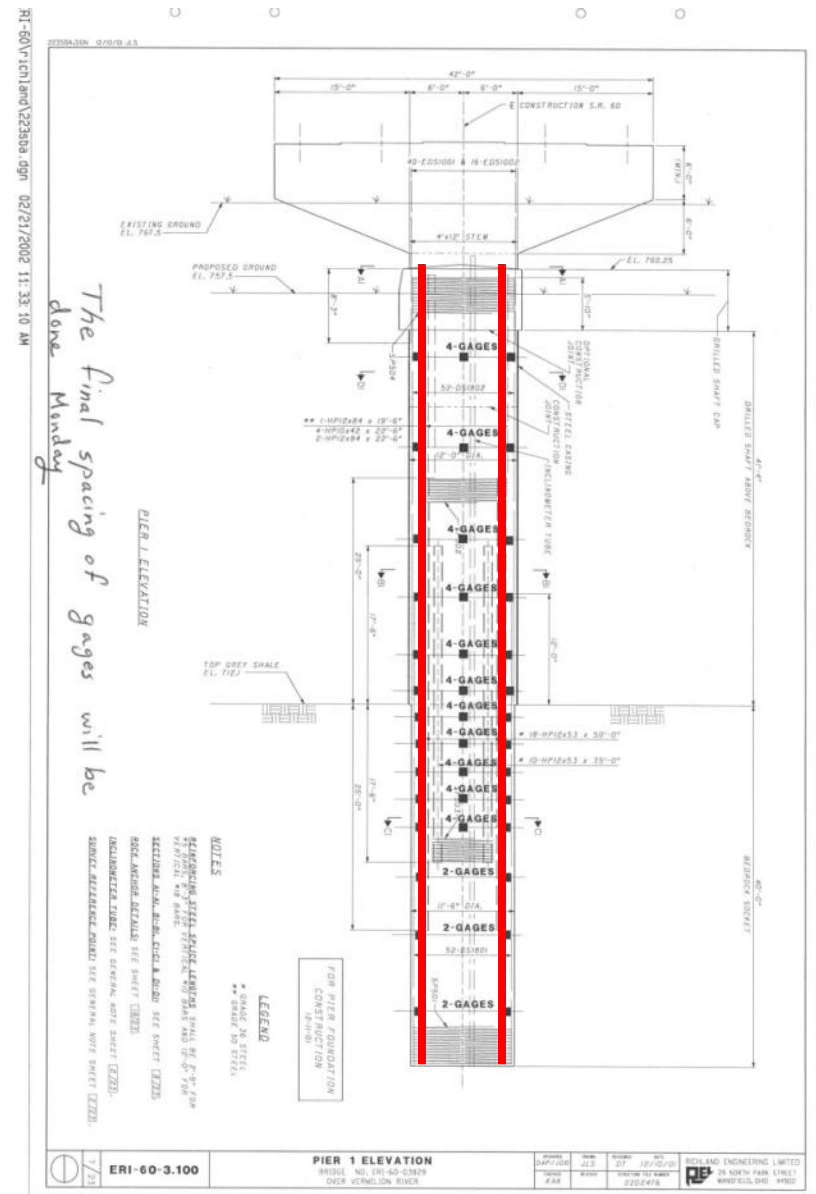

Pier 1
50 Sisterbar Strain Gages
2 inclinometers
1 Biaxial Tiltmeter

Pier 2
2 inclinometers

Pictures of Instrumentation Installation

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Pictures of Instrumentation Installation

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Pictures of Instrumentation Installation

Pictures of Pier 1 Instrumentation

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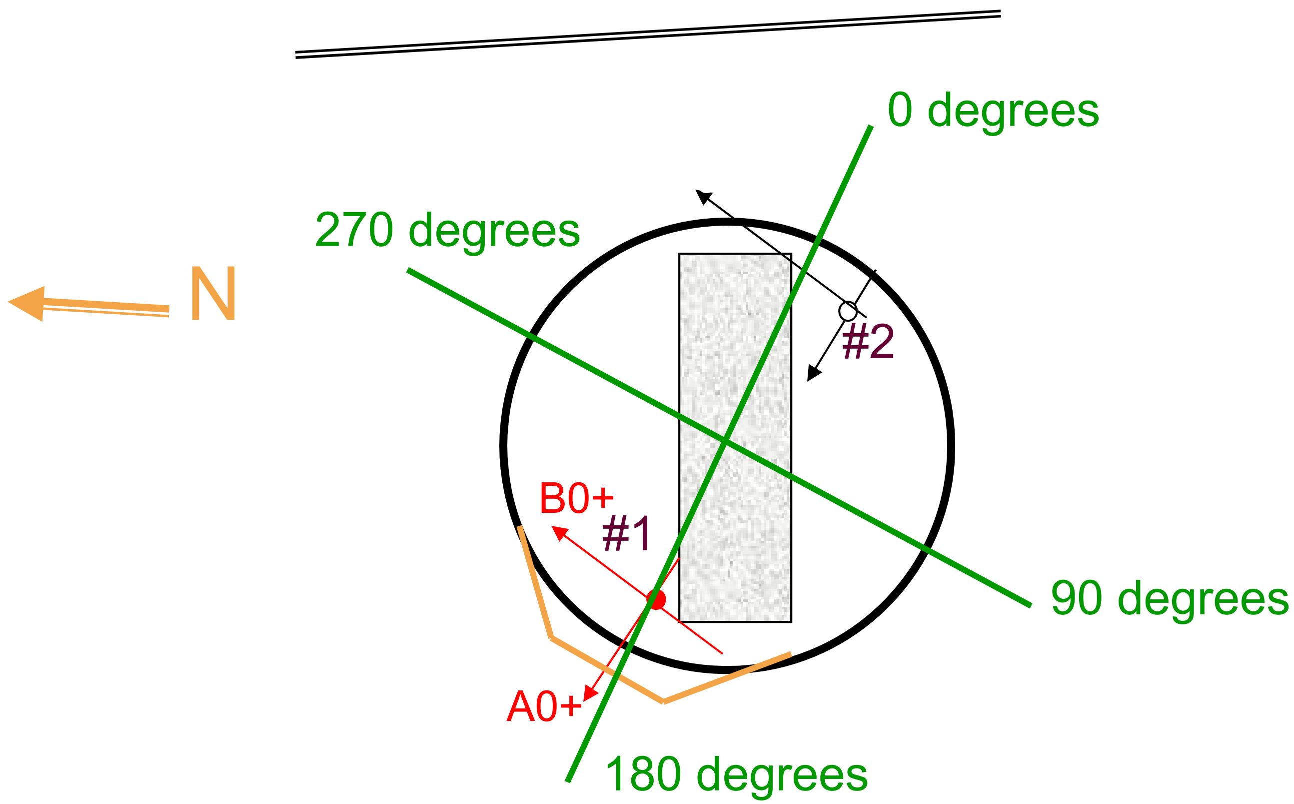
Instruments locations



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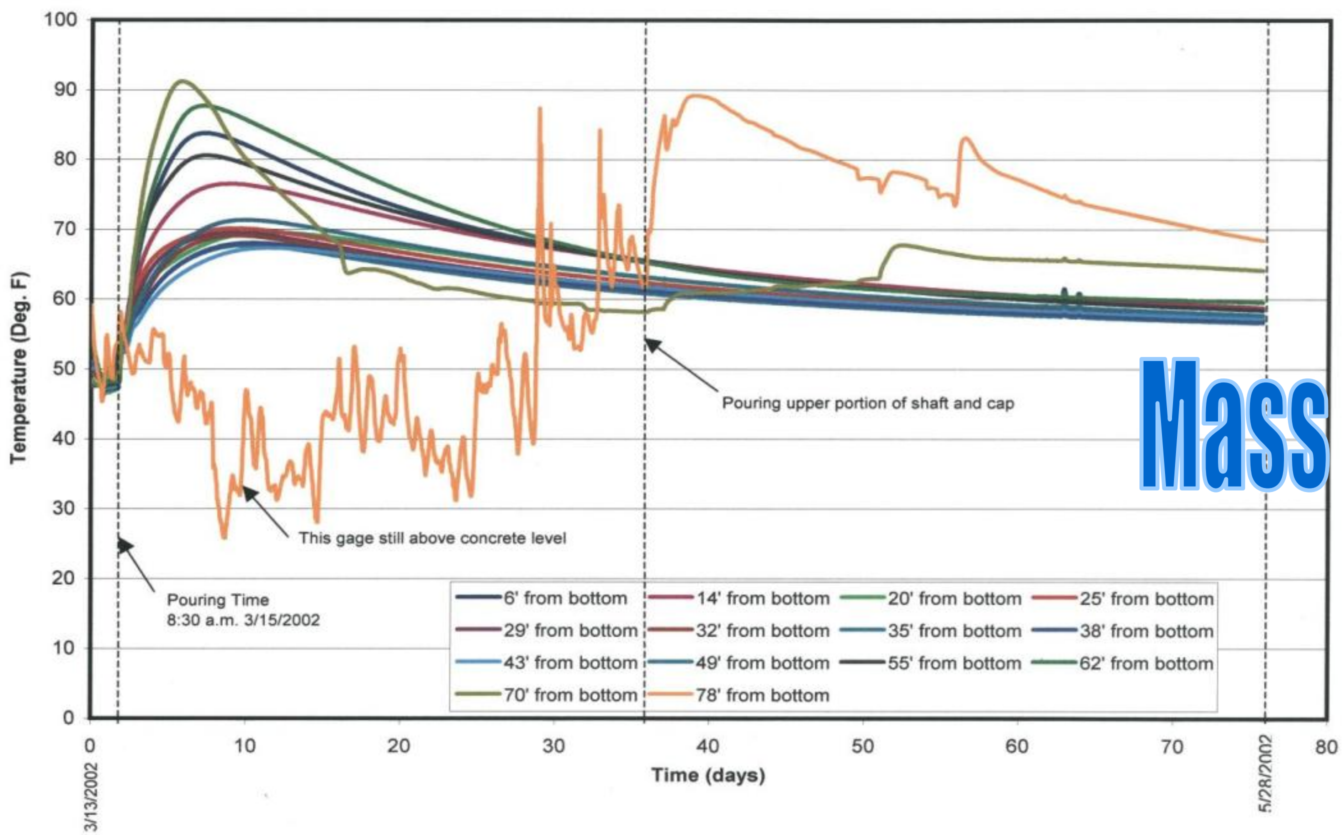
Temperature monitoring in Pier 1



Mass Pour

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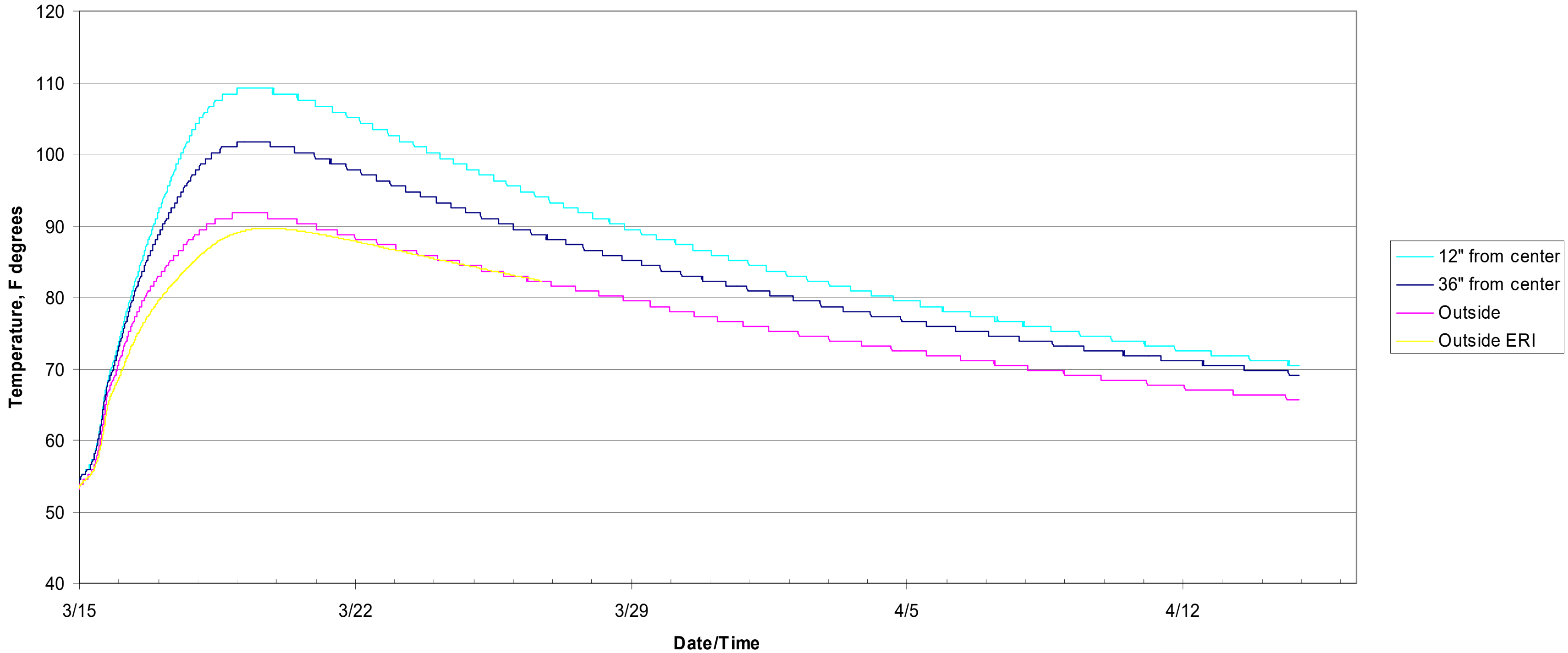
Temperature monitoring in Pier 1

Client: S.E. Johnson Construction Companies, Inc. **Report Date: May 15, 2002**
Project: ODOT 5(01) SR 60 Birmingham, Ohio **CTL Project No. 026002EV**
Temperature vs Time Caisson #1, 60.5 ft from bottom



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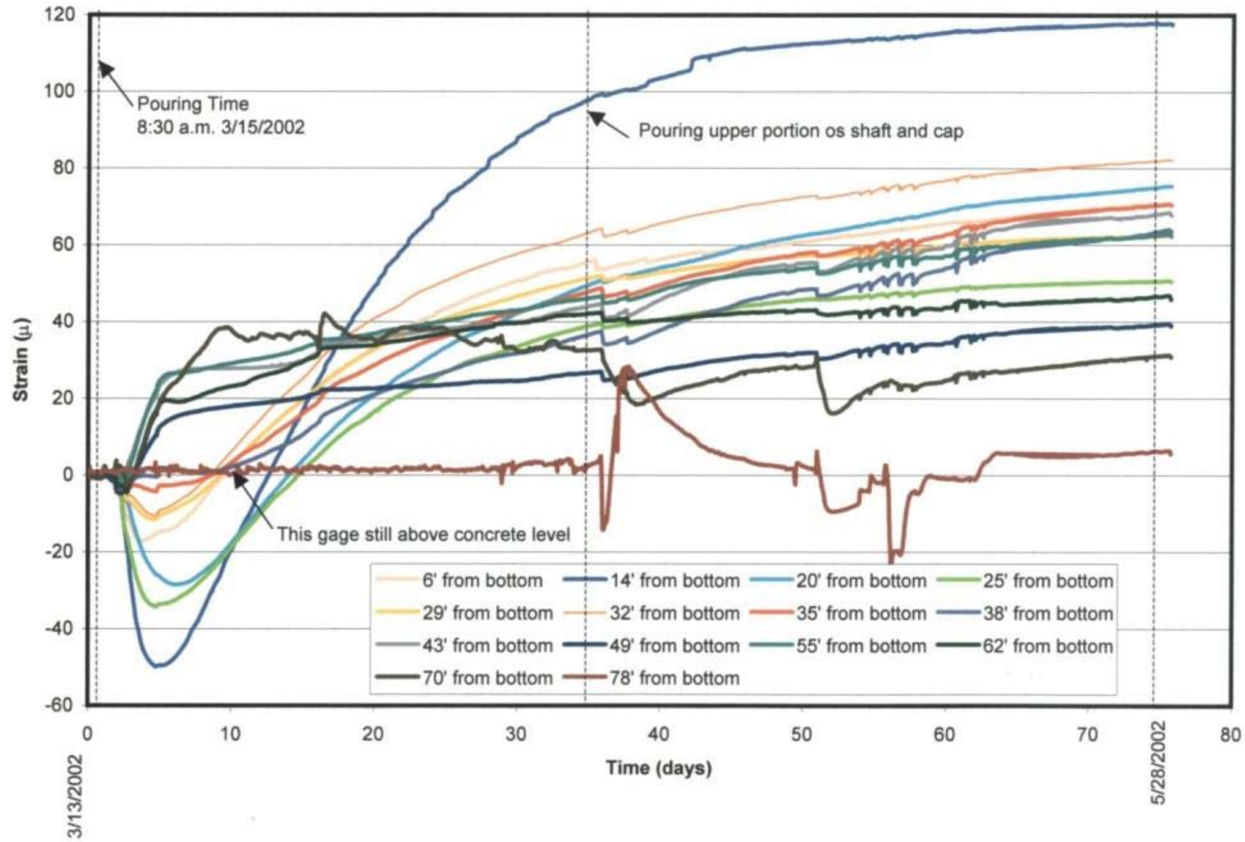
Strains in Pier 1 (East-West)
3/13 ~ 5/28/02



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Anchor Tensioning- Pier 1

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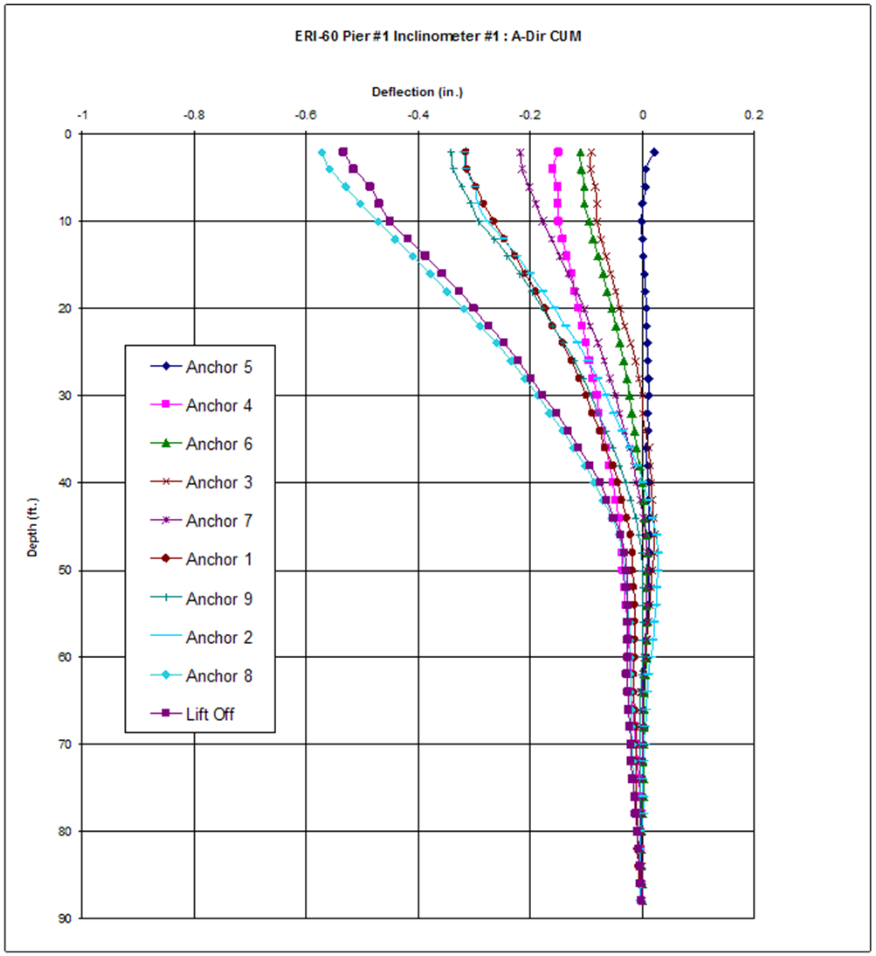
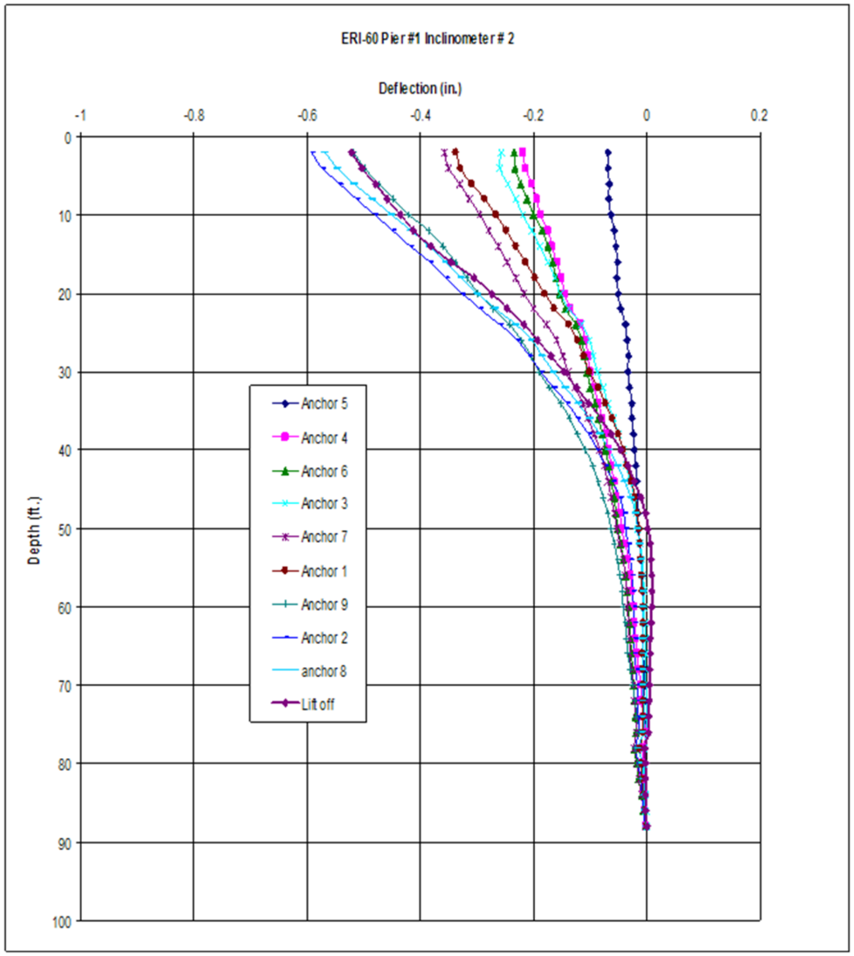
Deflection with depth during Tensioning of Pier 1





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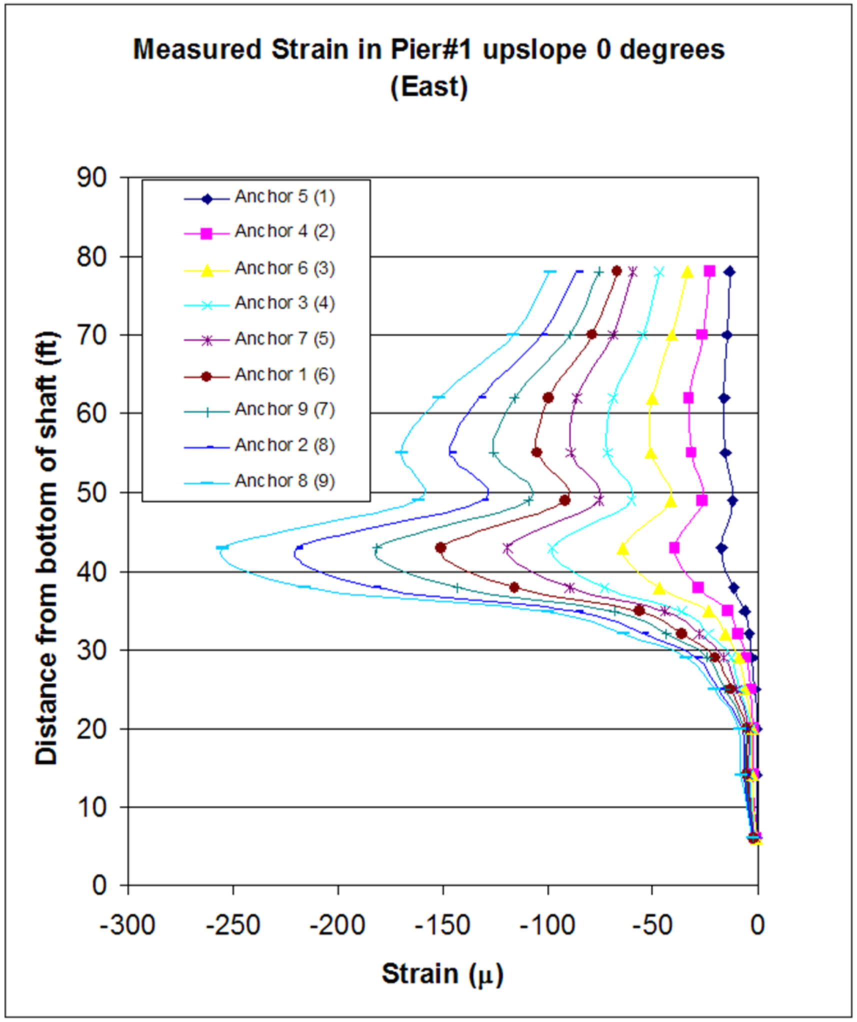
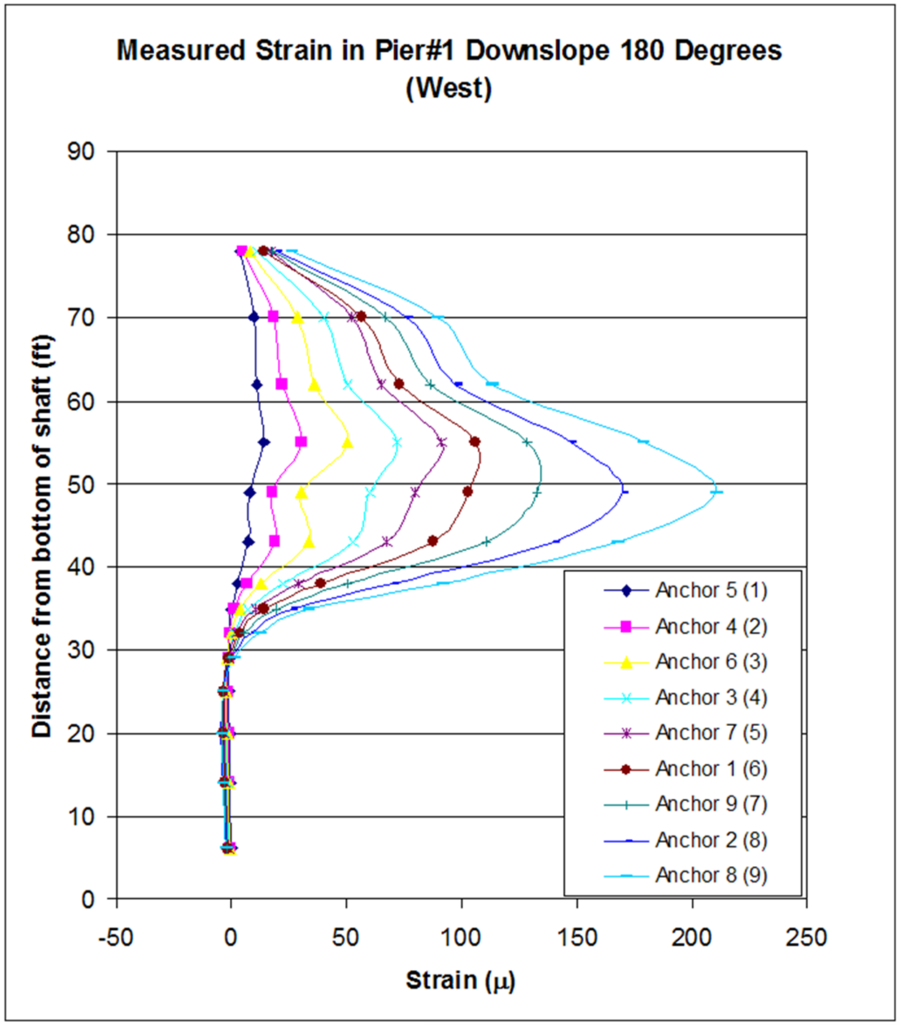
Strains during anchor tensioning in Pier 1





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Long Term monitoring Results 5/30/2002 ~ 8/21/2002 After opening Bridge to Traffic

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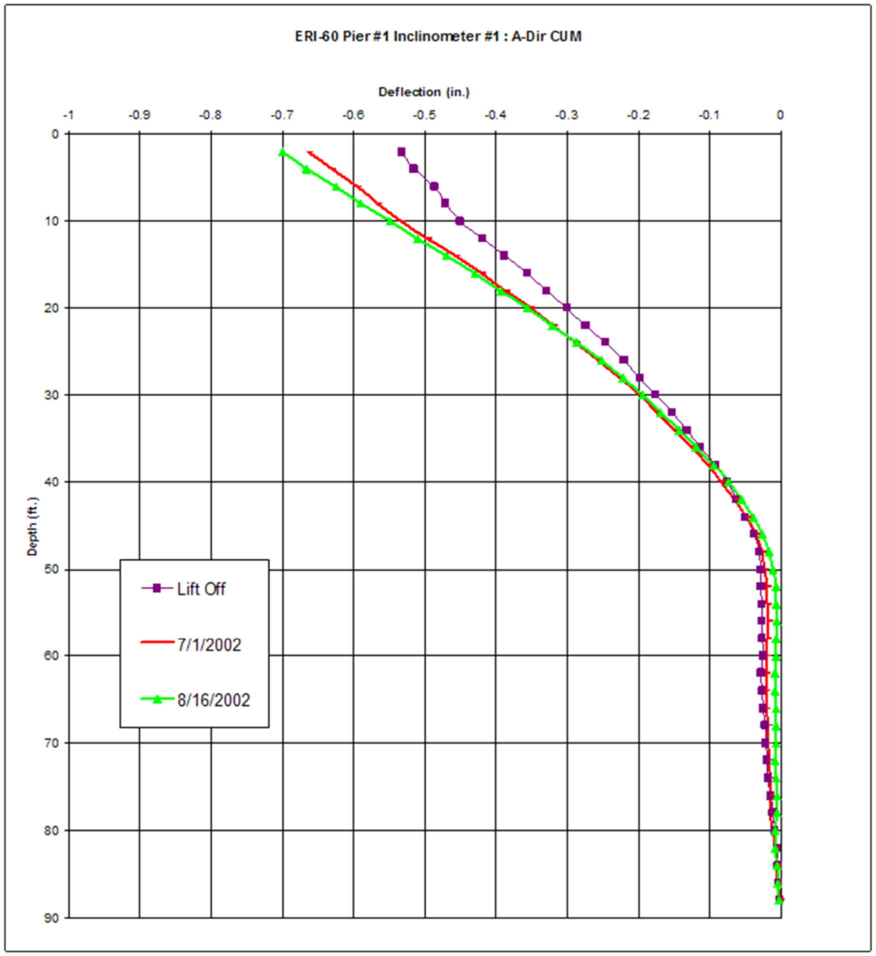
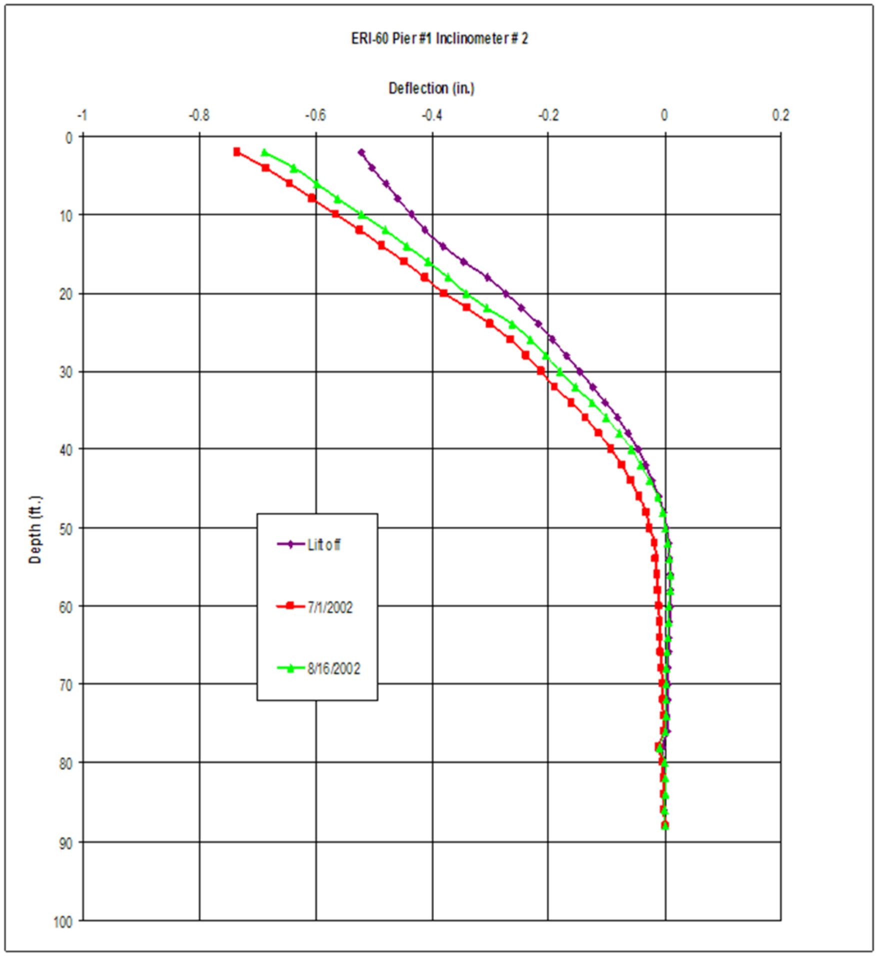
Deflection in Pier 1





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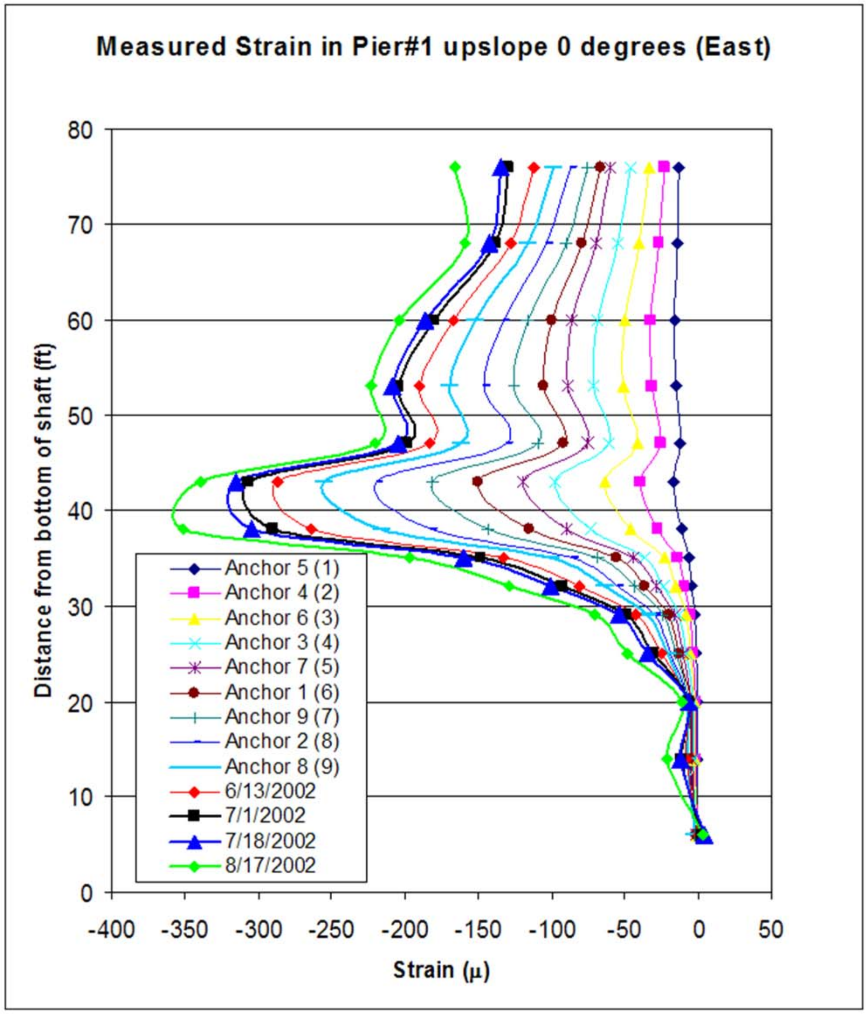
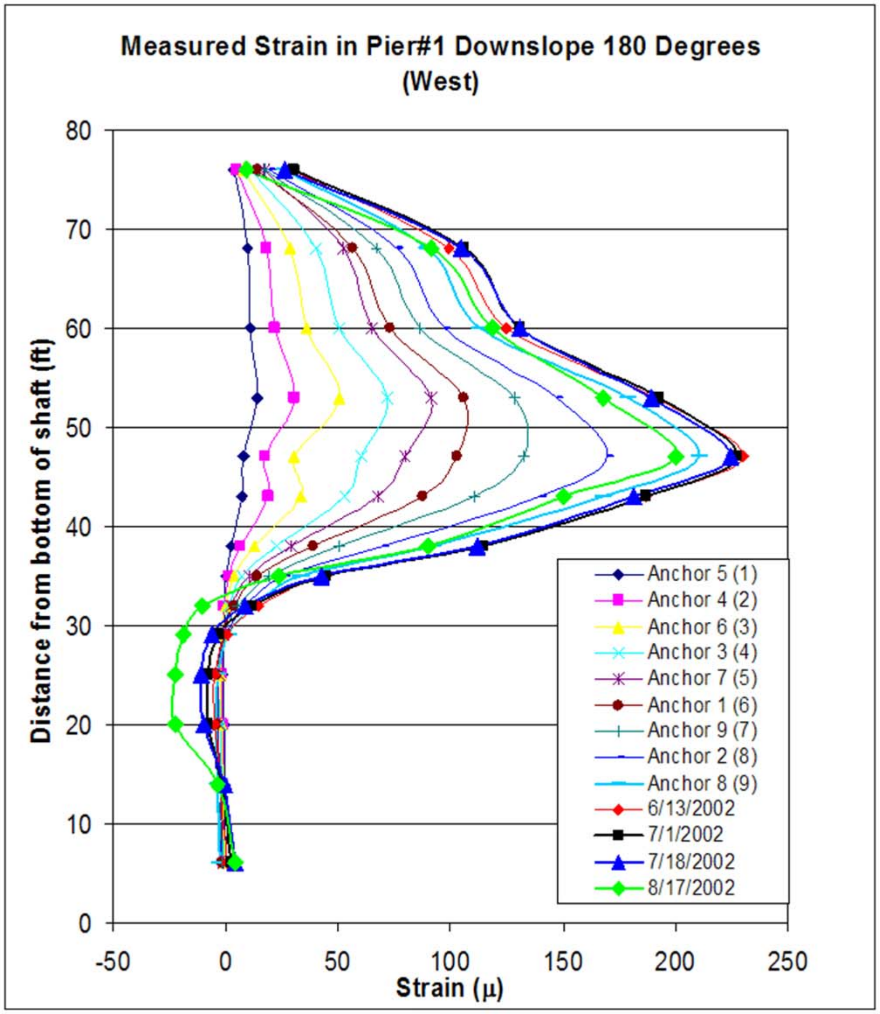
Strain vs. Time in Pier 1 (East-West Direction)





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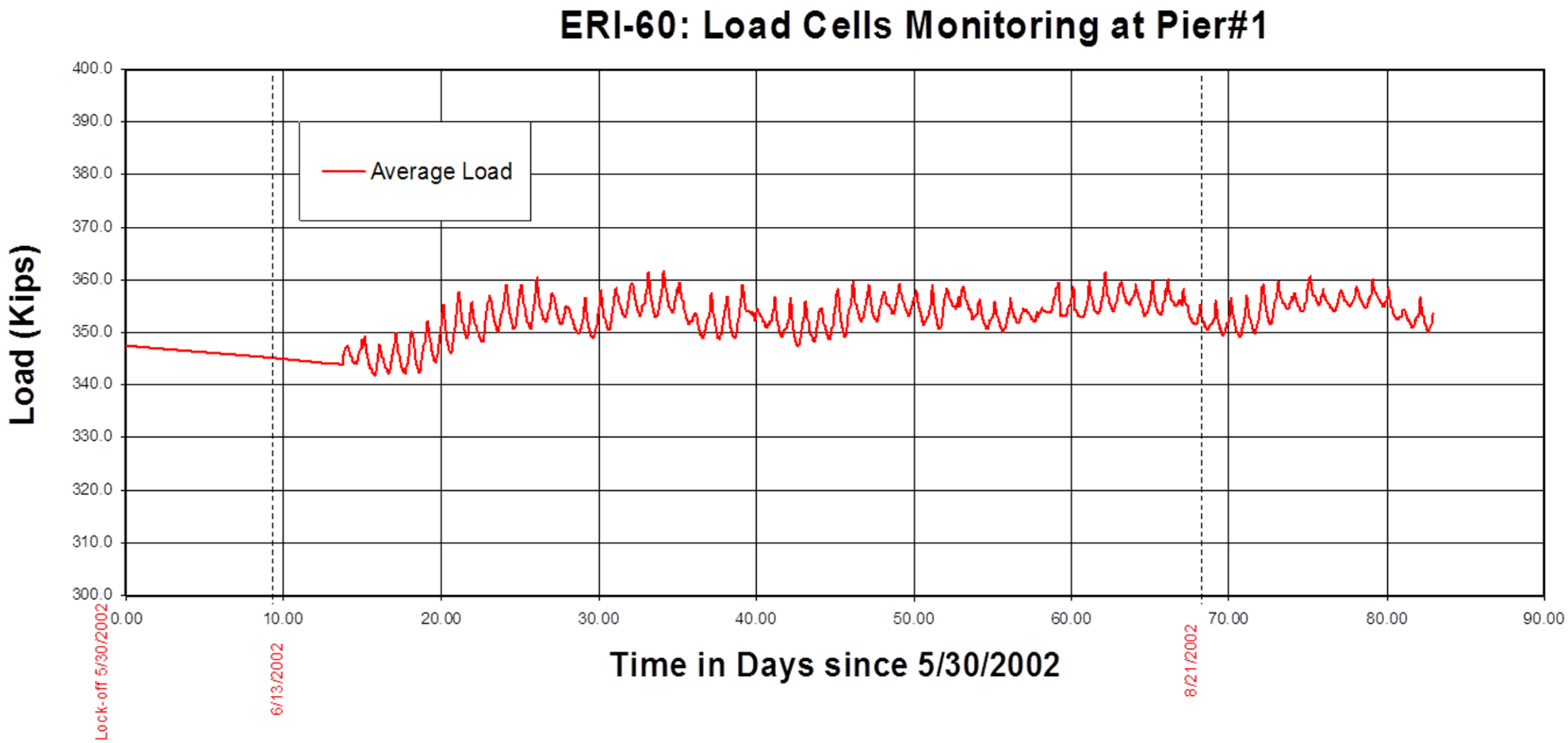
Load Cell Measurements in Pier 1 Anchors



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Long Term monitoring Results

5/30/2002 ~ 5/17/2018

4 Earth Inclinometers were added near the Rear Abutment and Piers 1 and 2

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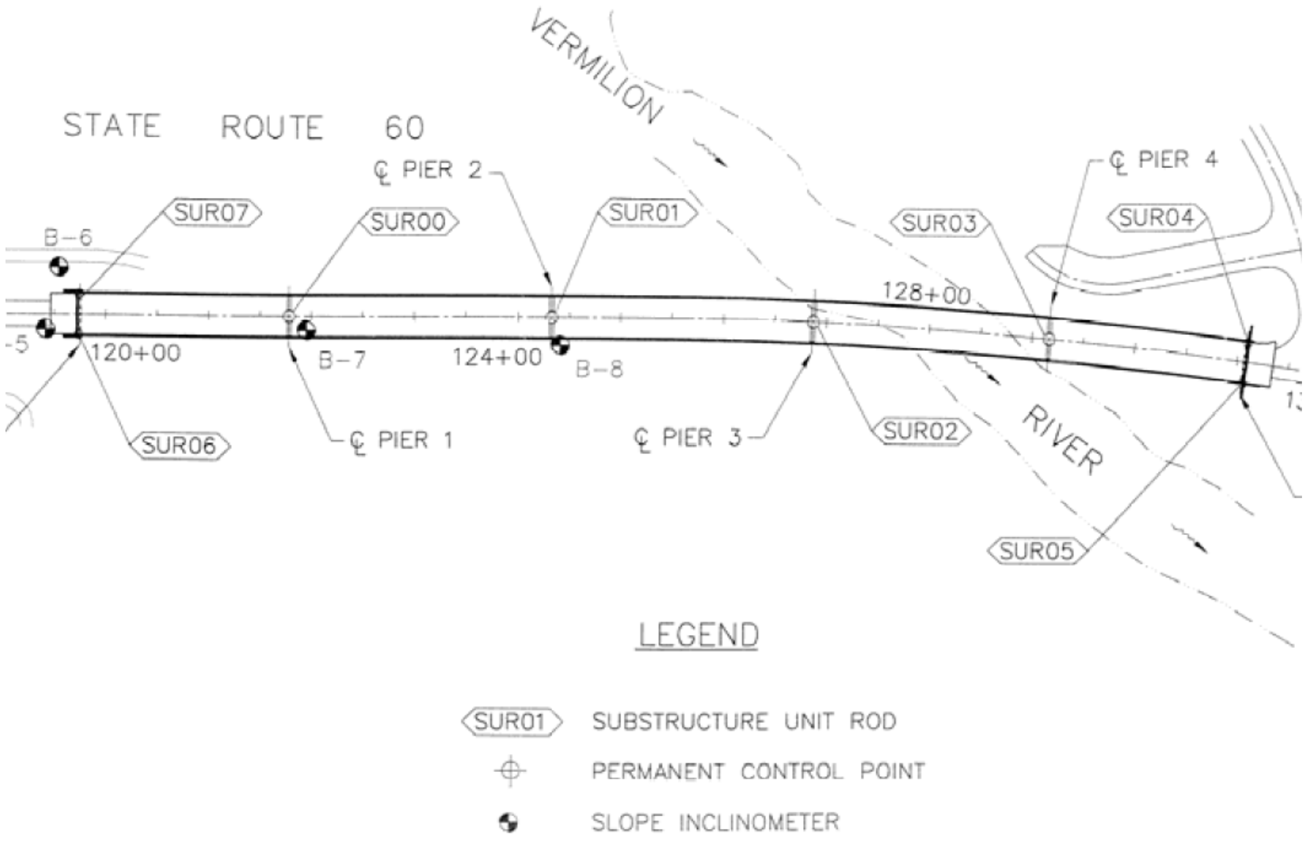
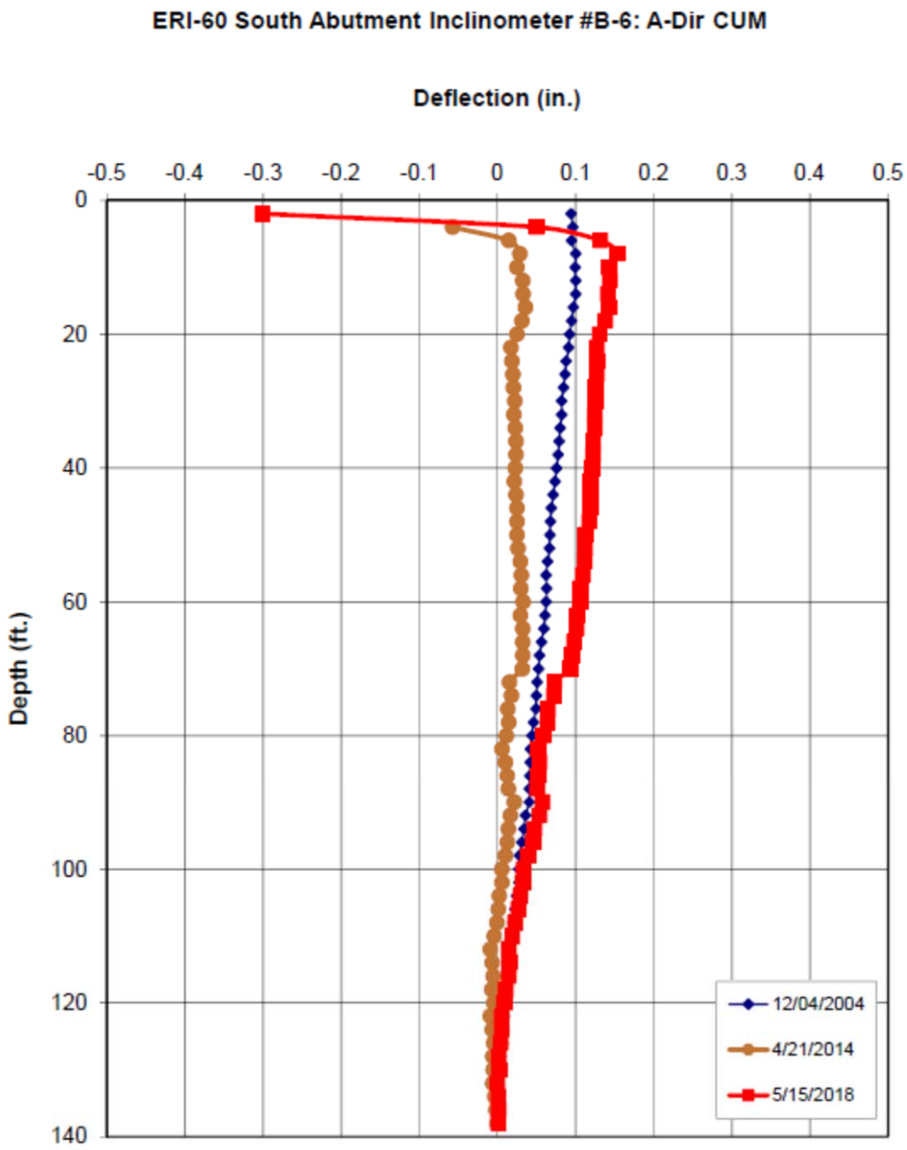
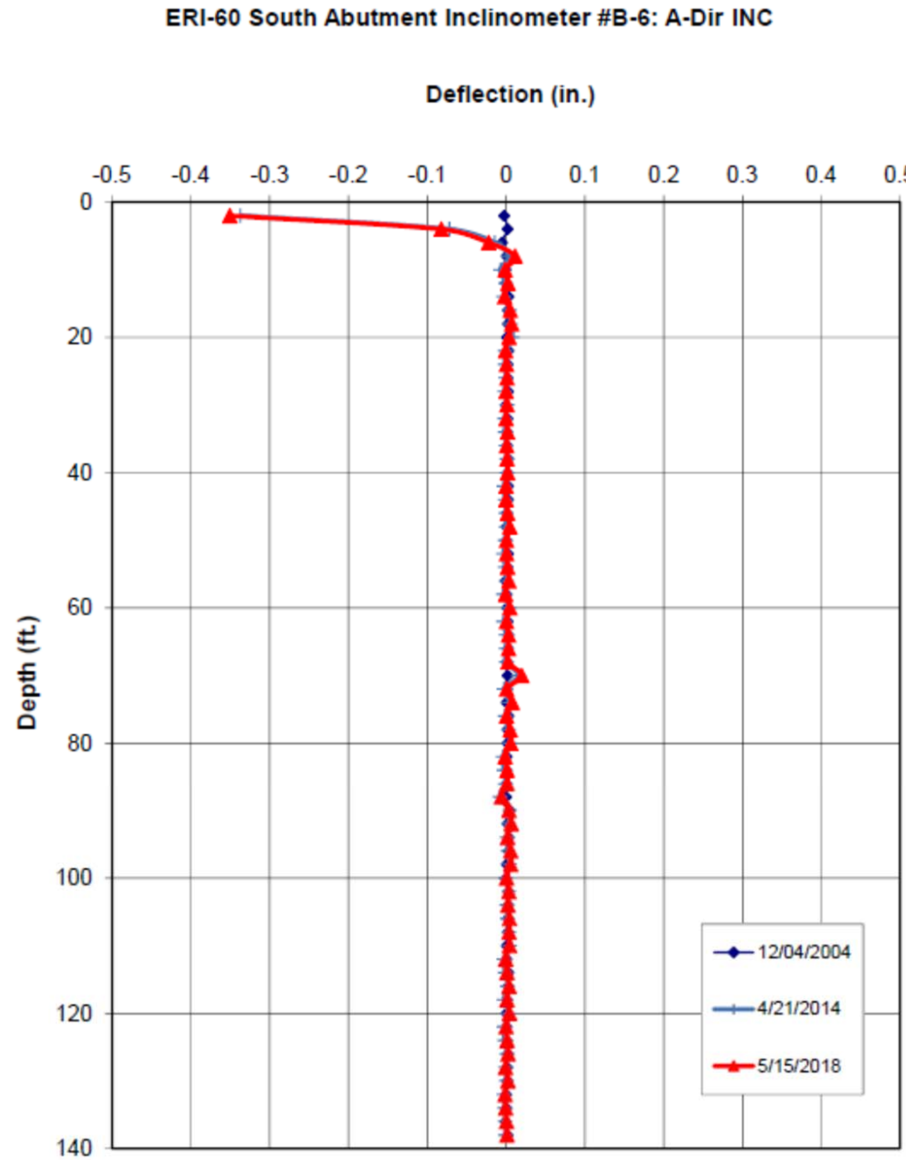
Locations of Earth Inclinometers







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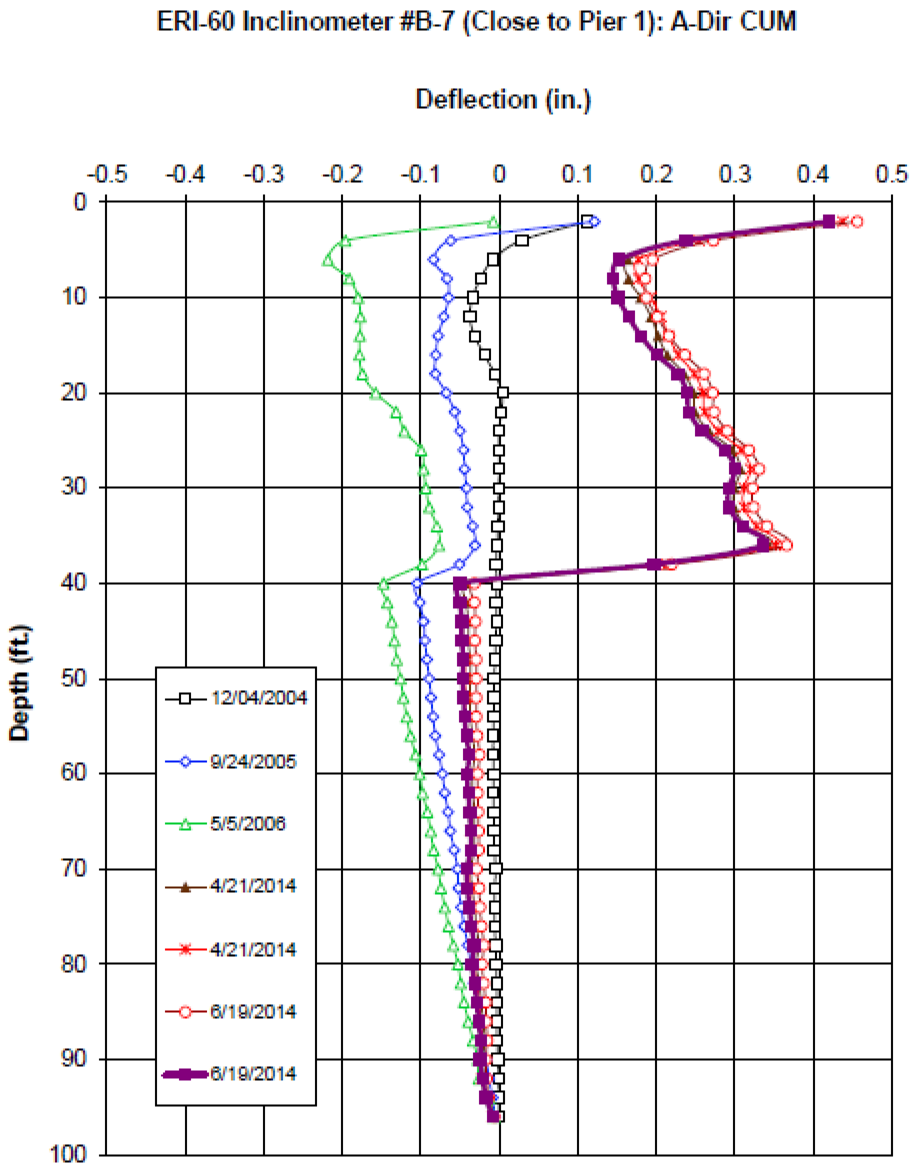

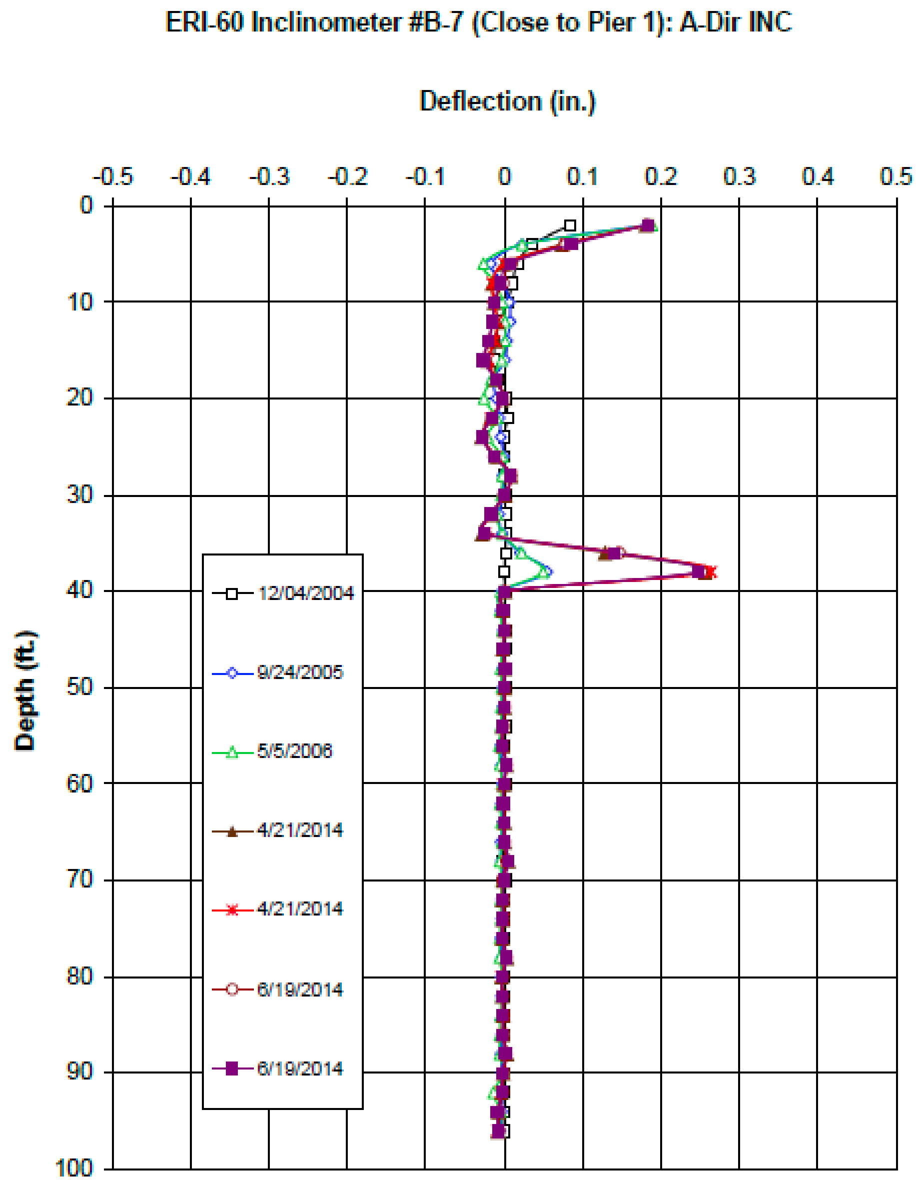

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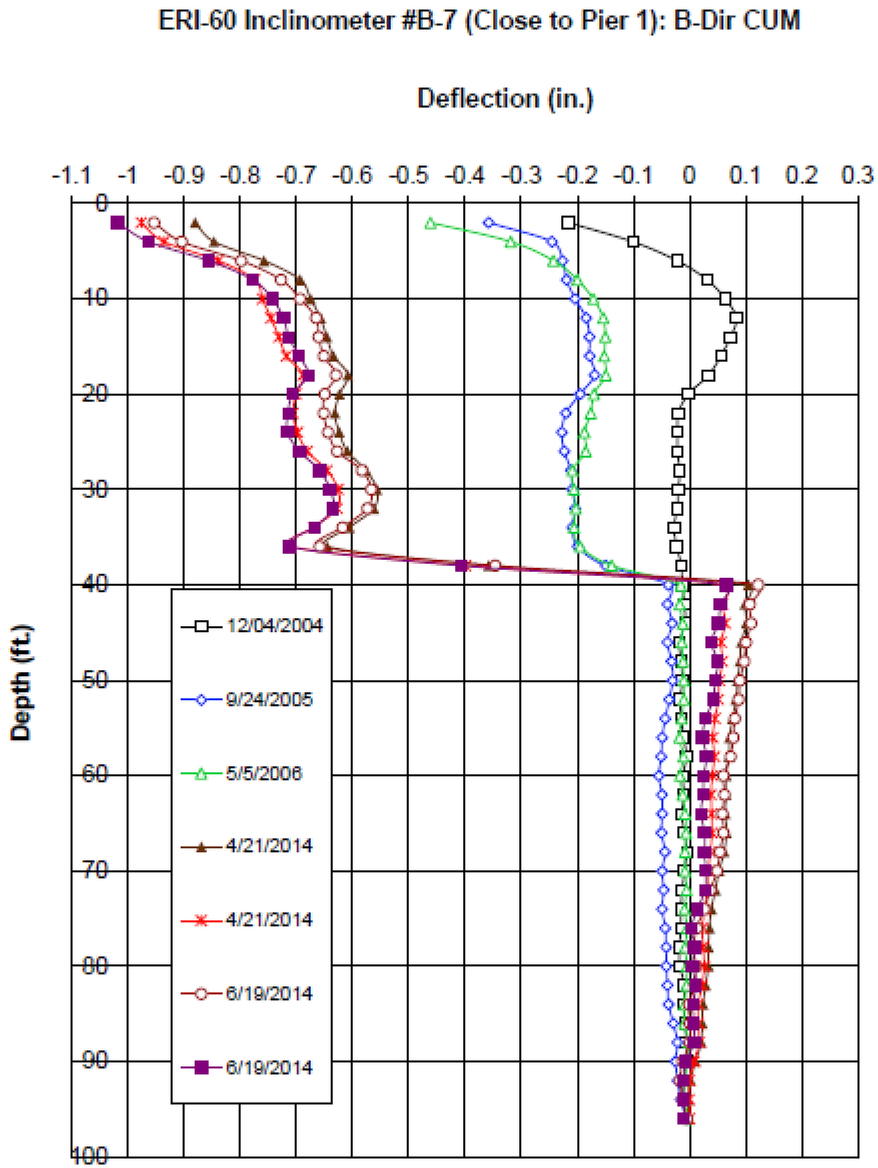
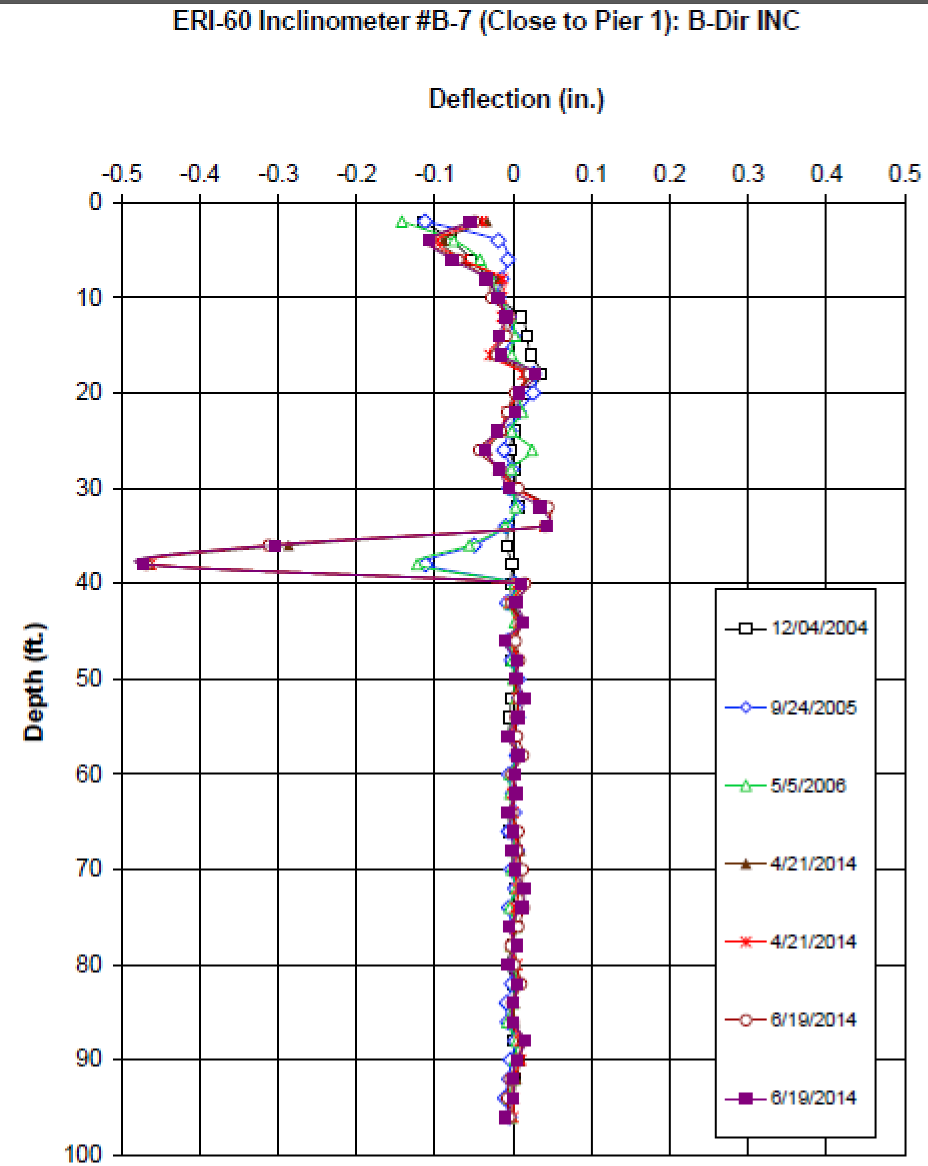
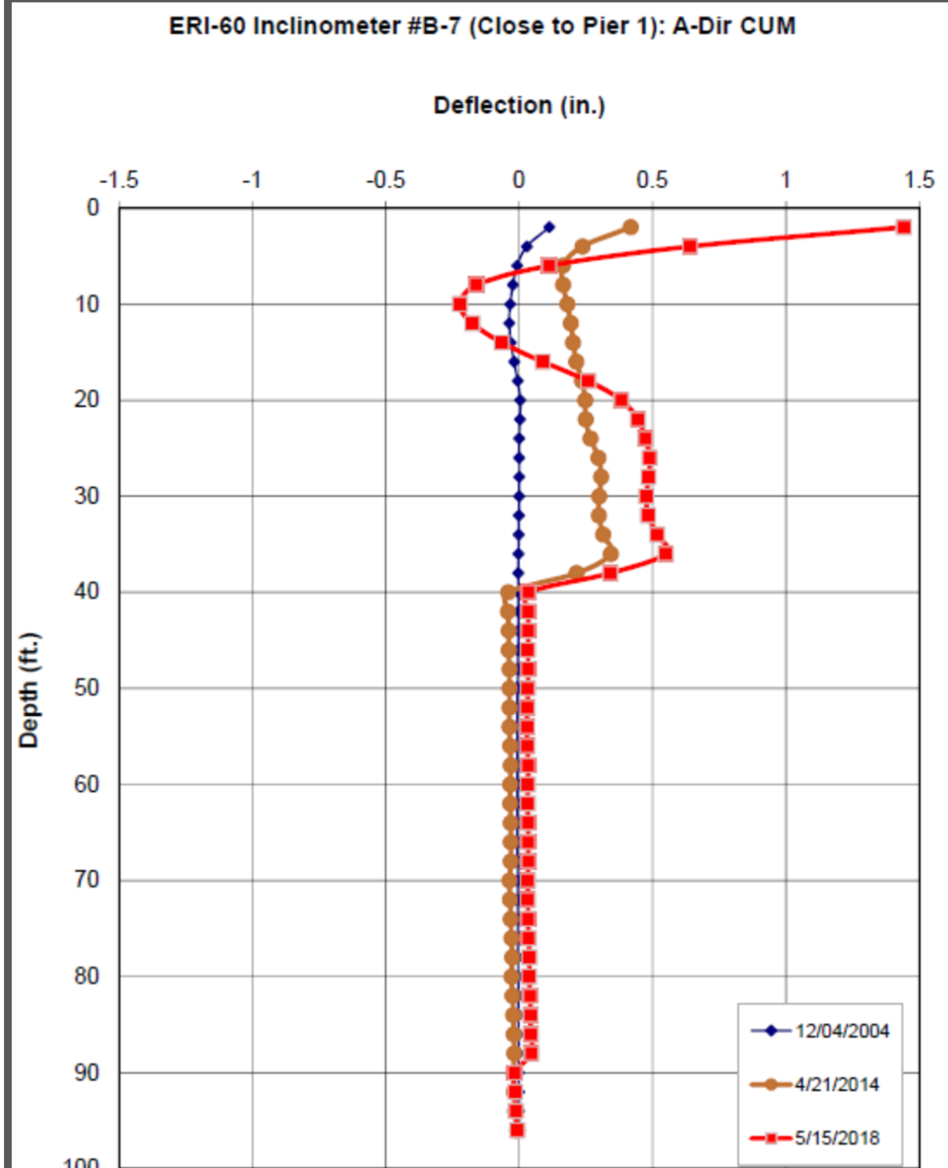
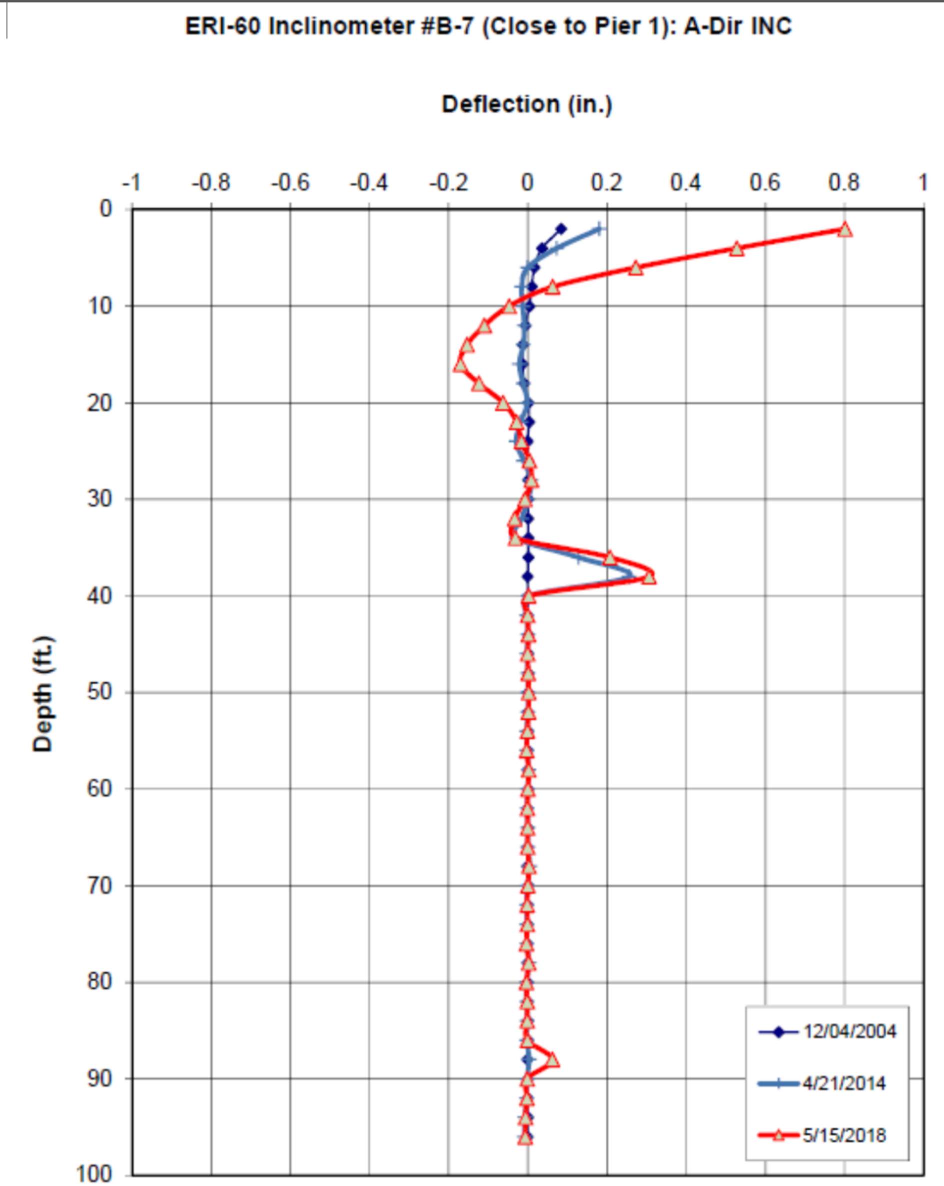

ERI-60 Inclinometer #B-7 (Close to Pier 1): B-Dir CUM
Deflection (in.)
-1.1 -1 -0.9 -0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3
Depth (ft.)
0 10 20 30 40 50 60 70 80 90 100
12/04/2004
9/24/2005
5/5/2006
4/21/2014
4/21/2014
6/19/2014
6/19/2014


ERI-60 Inclinometer #B-7 (Close to Pier 1): B-Dir INC
Deflection (in.)
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5
Depth (ft.)
0 10 20 30 40 50 60 70 80 90 100
12/04/2004
9/24/2005
5/5/2006
4/21/2014
4/21/2014
6/19/2014
6/19/2014





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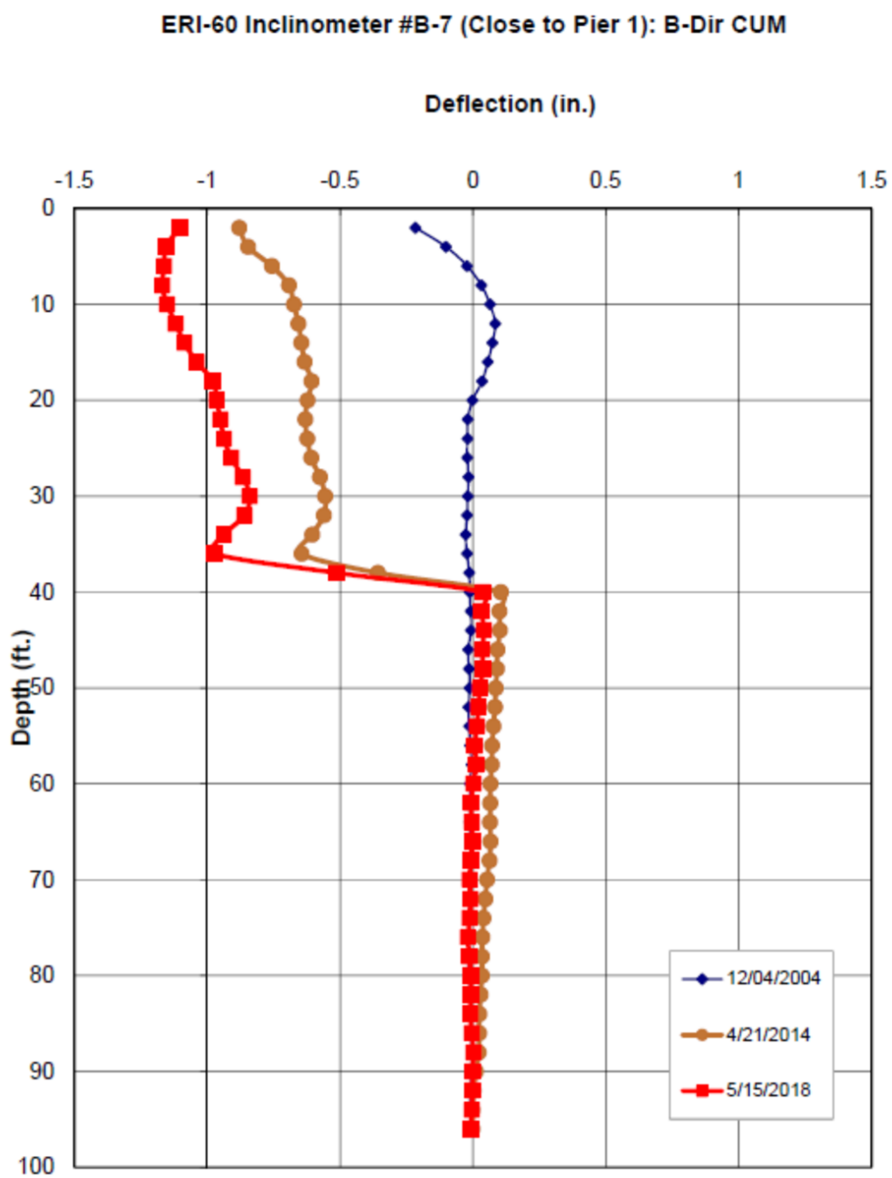

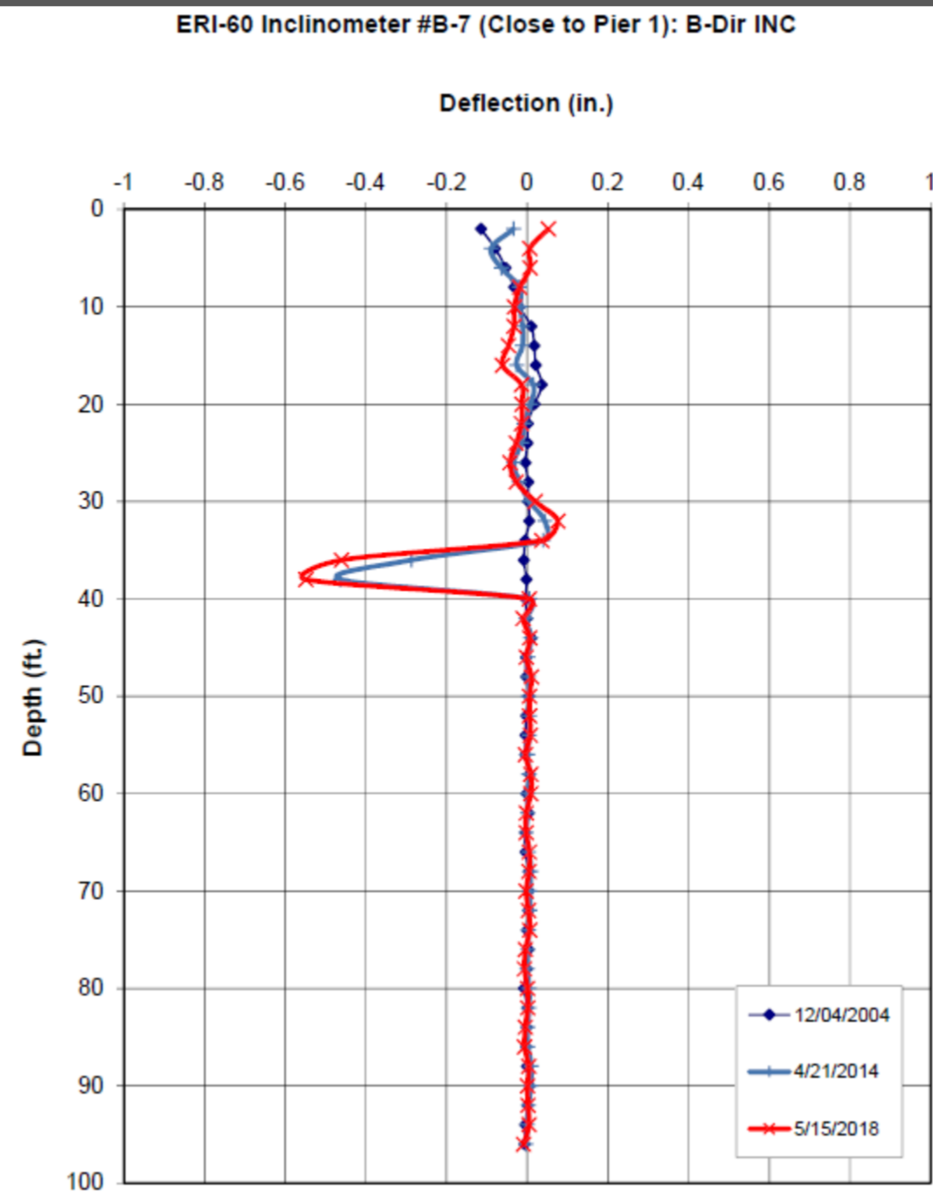

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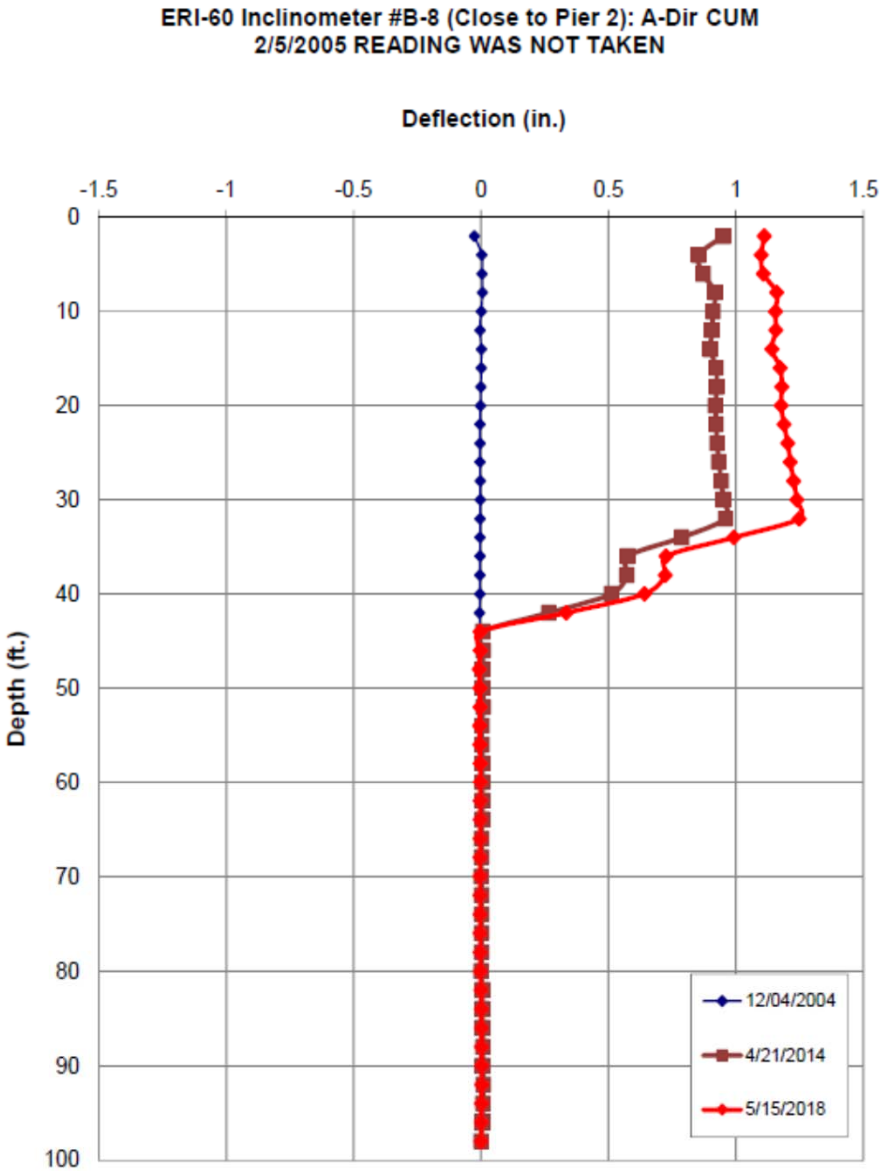

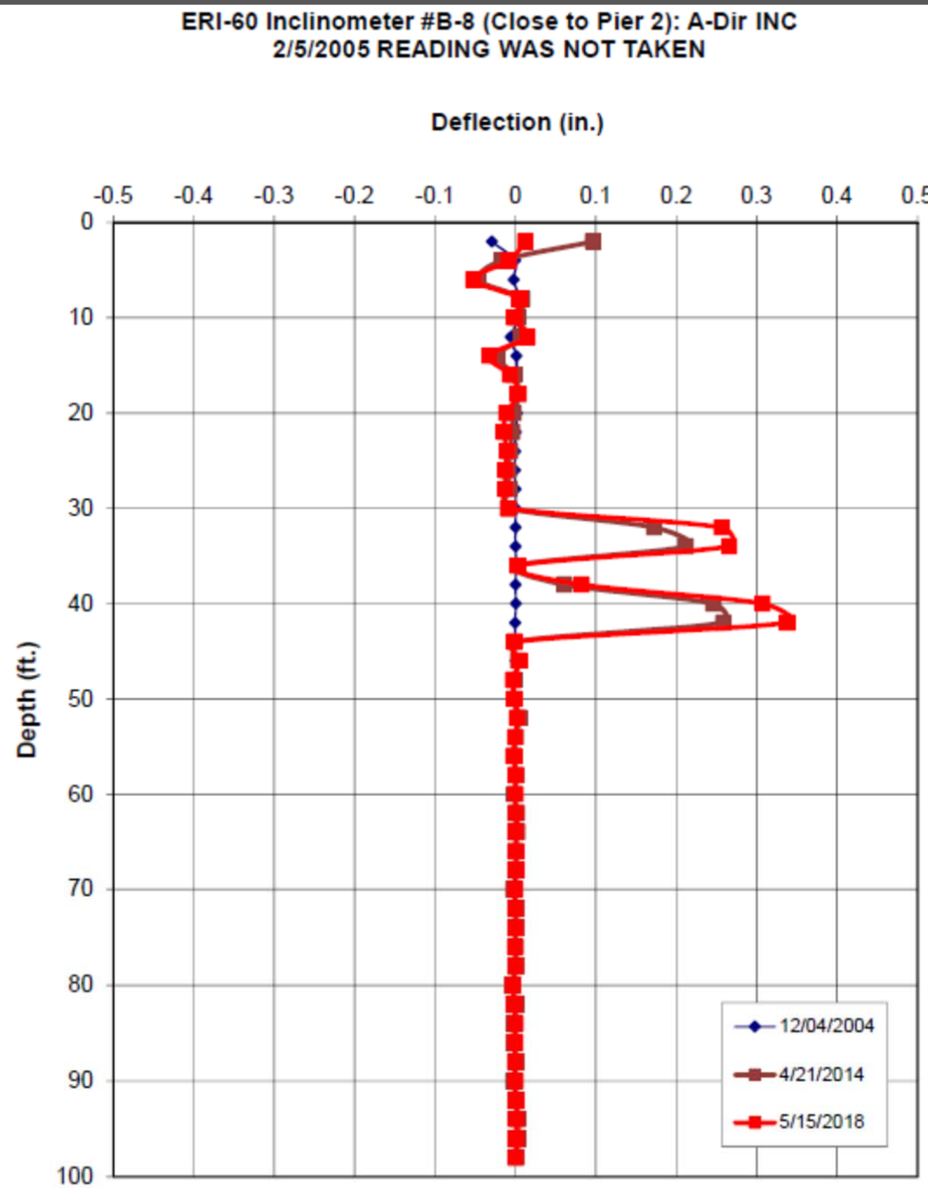

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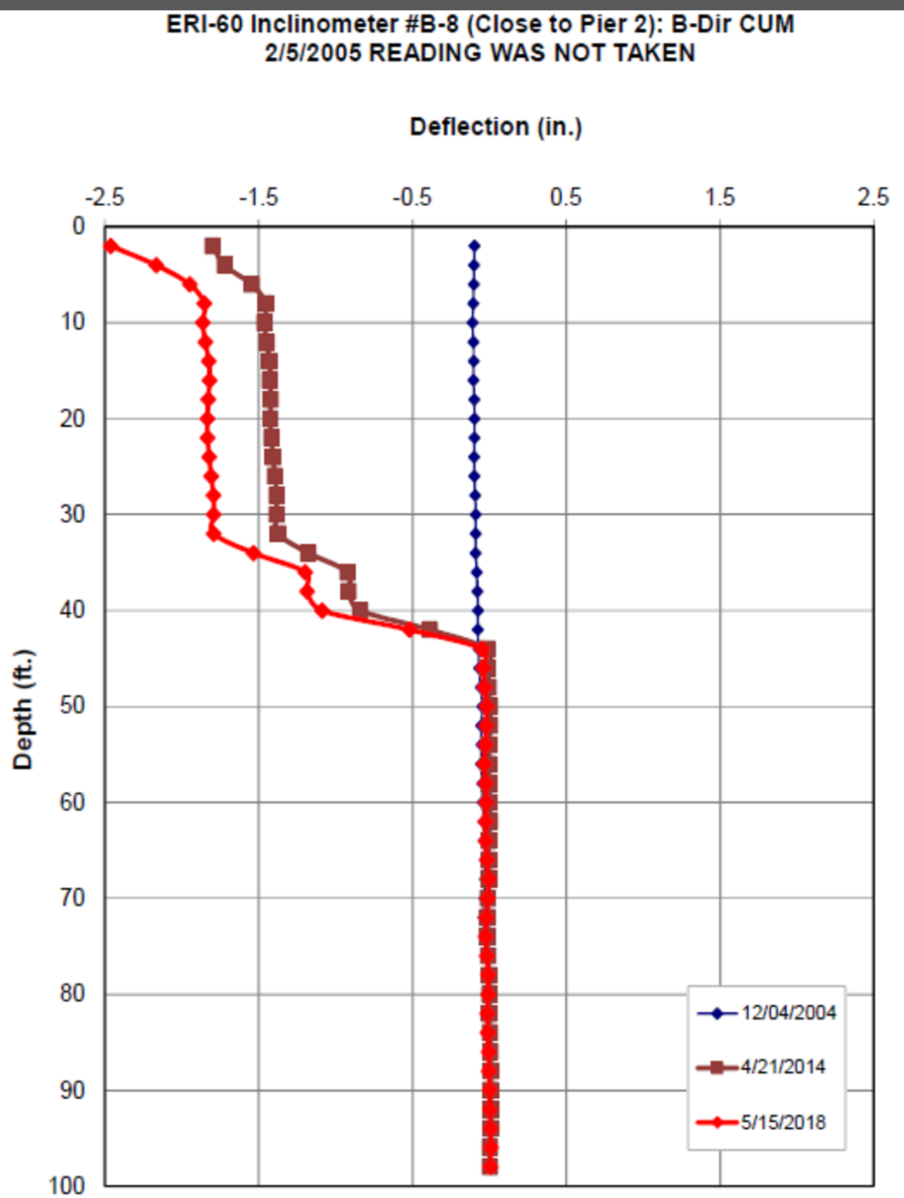

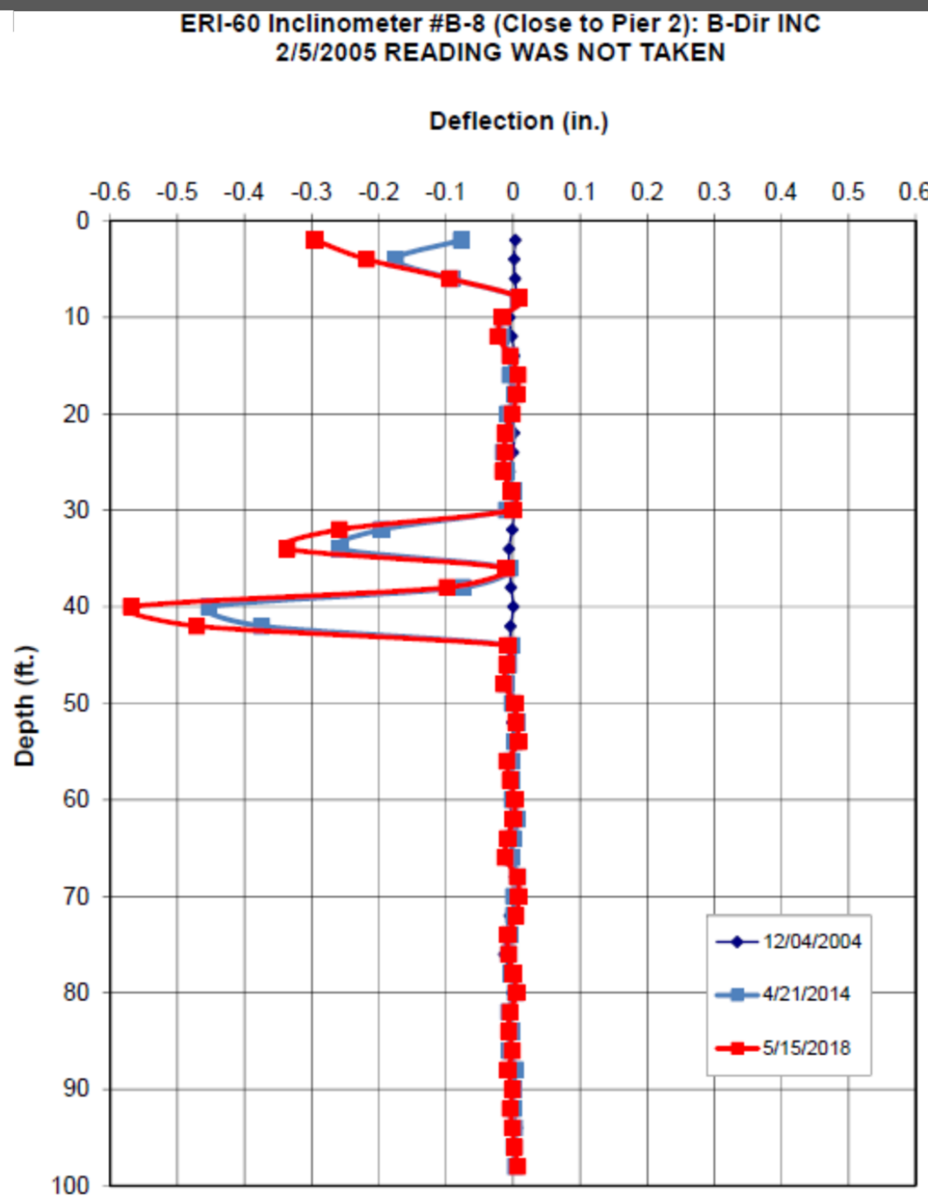

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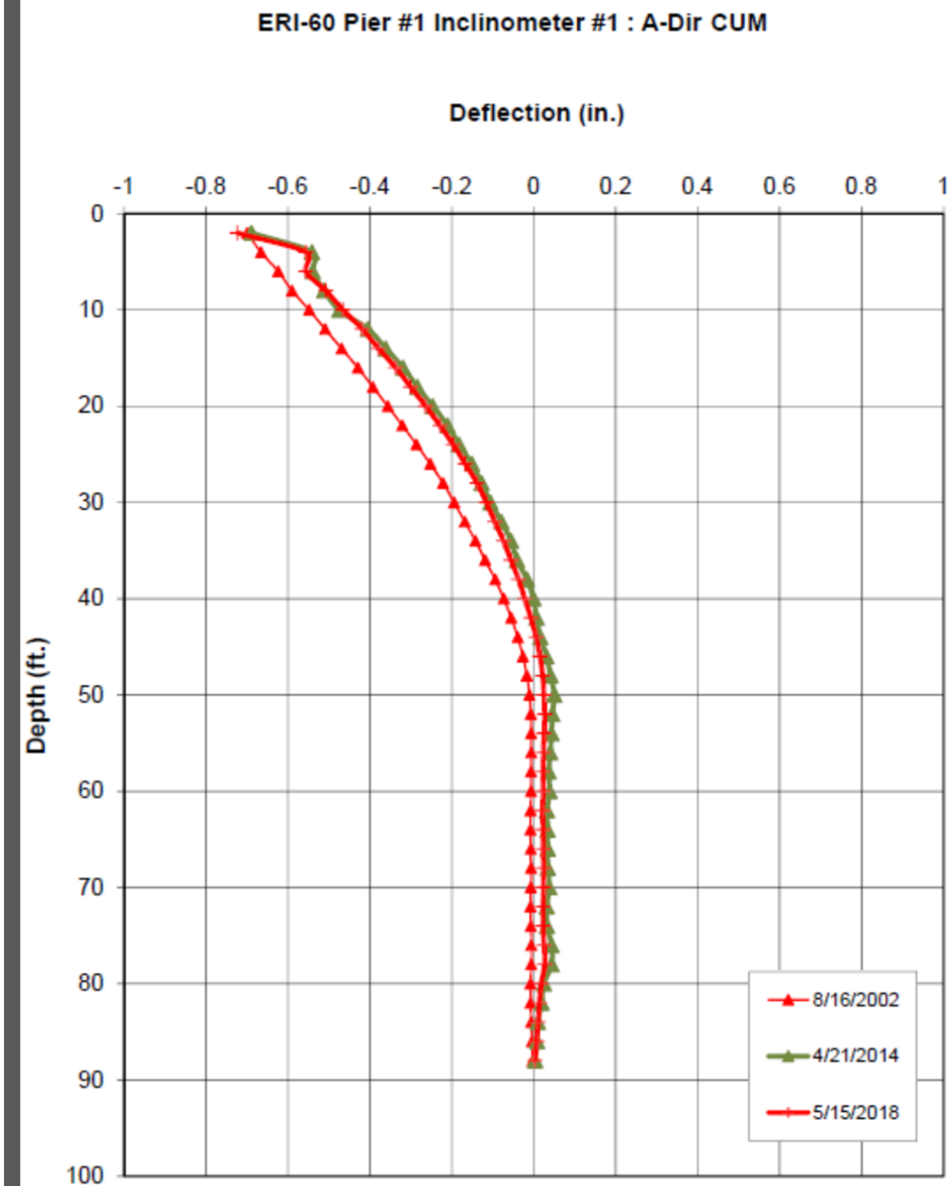

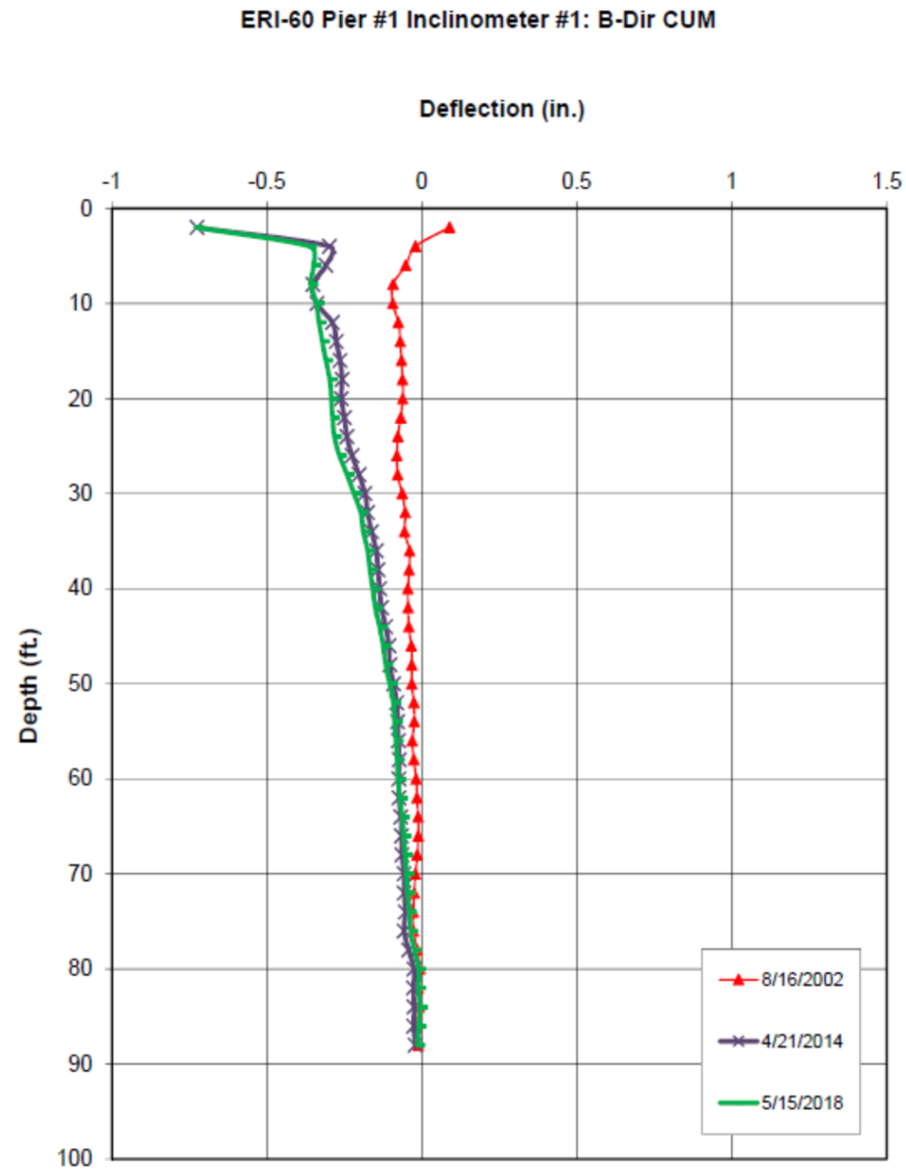

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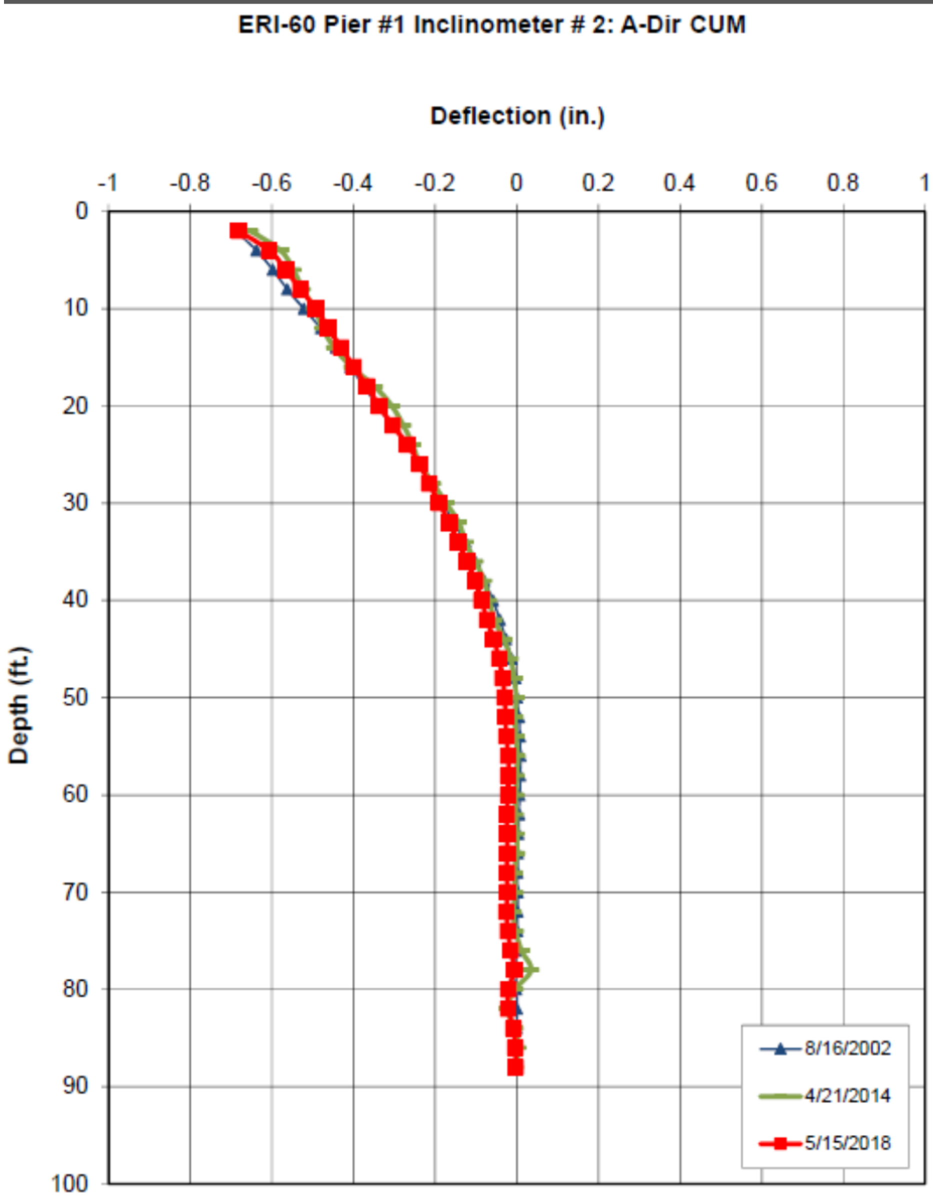

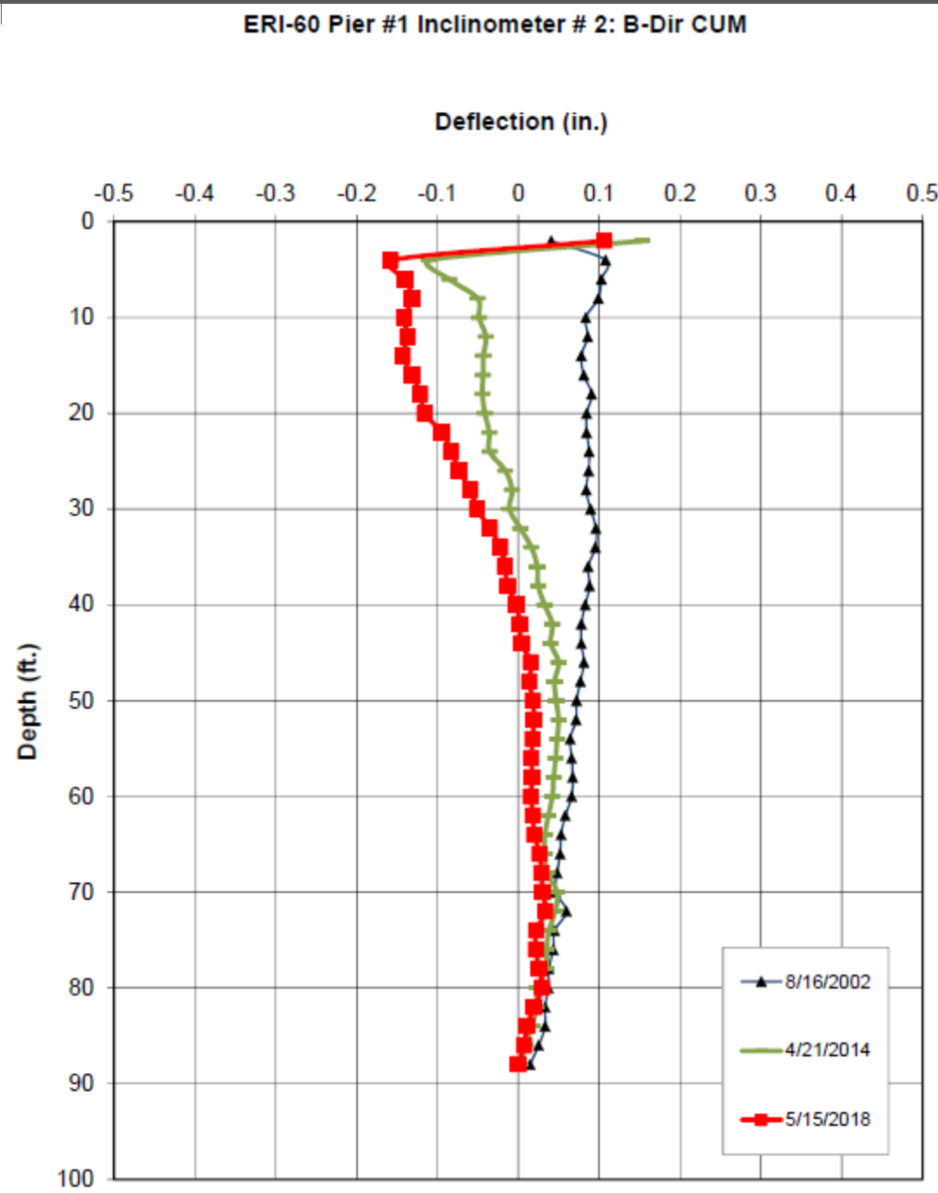

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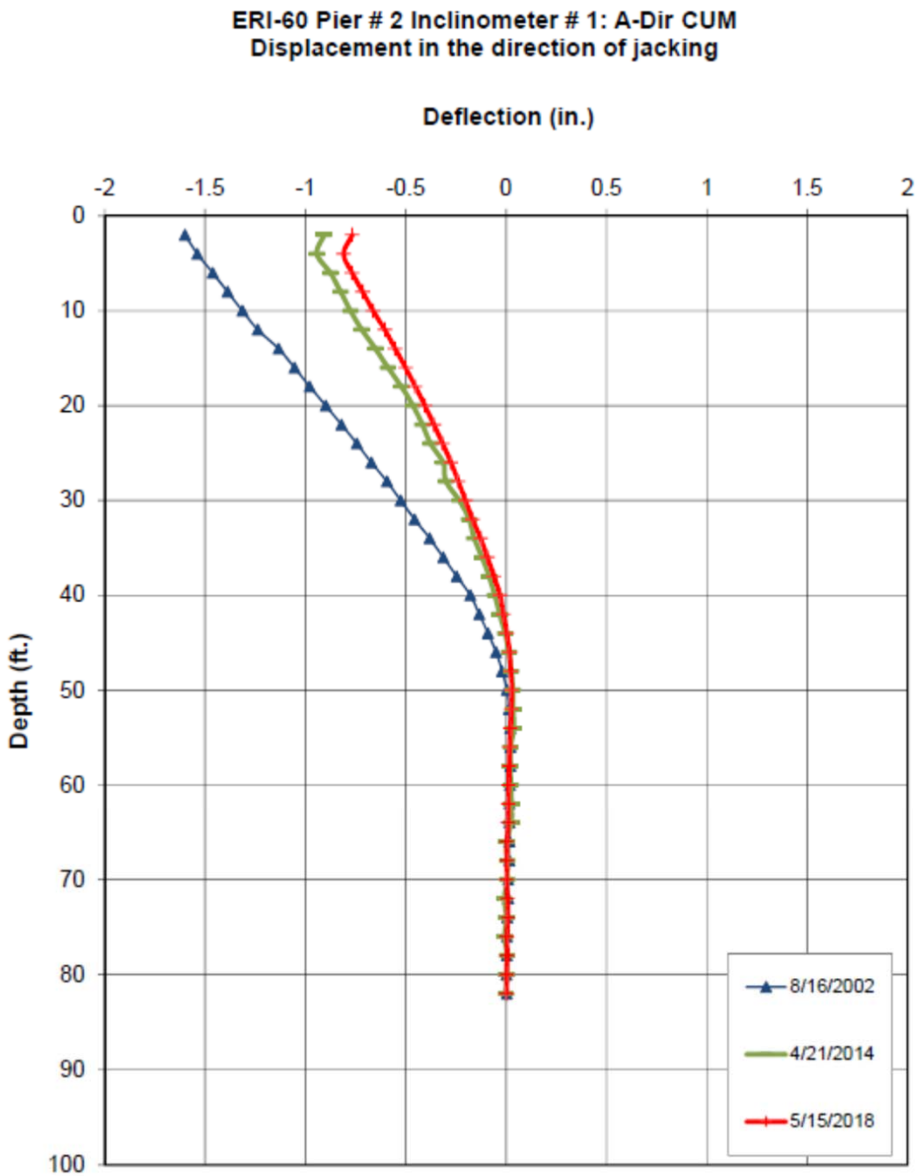

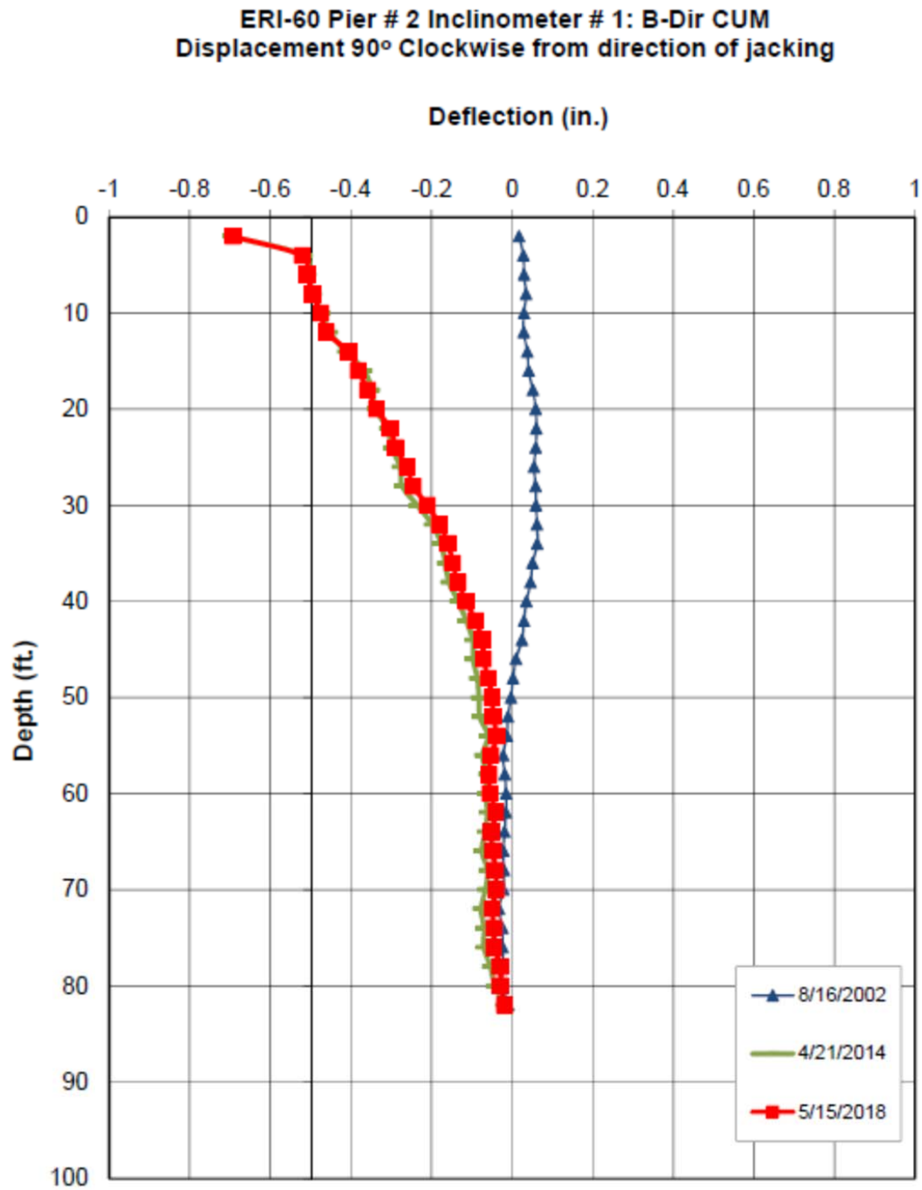

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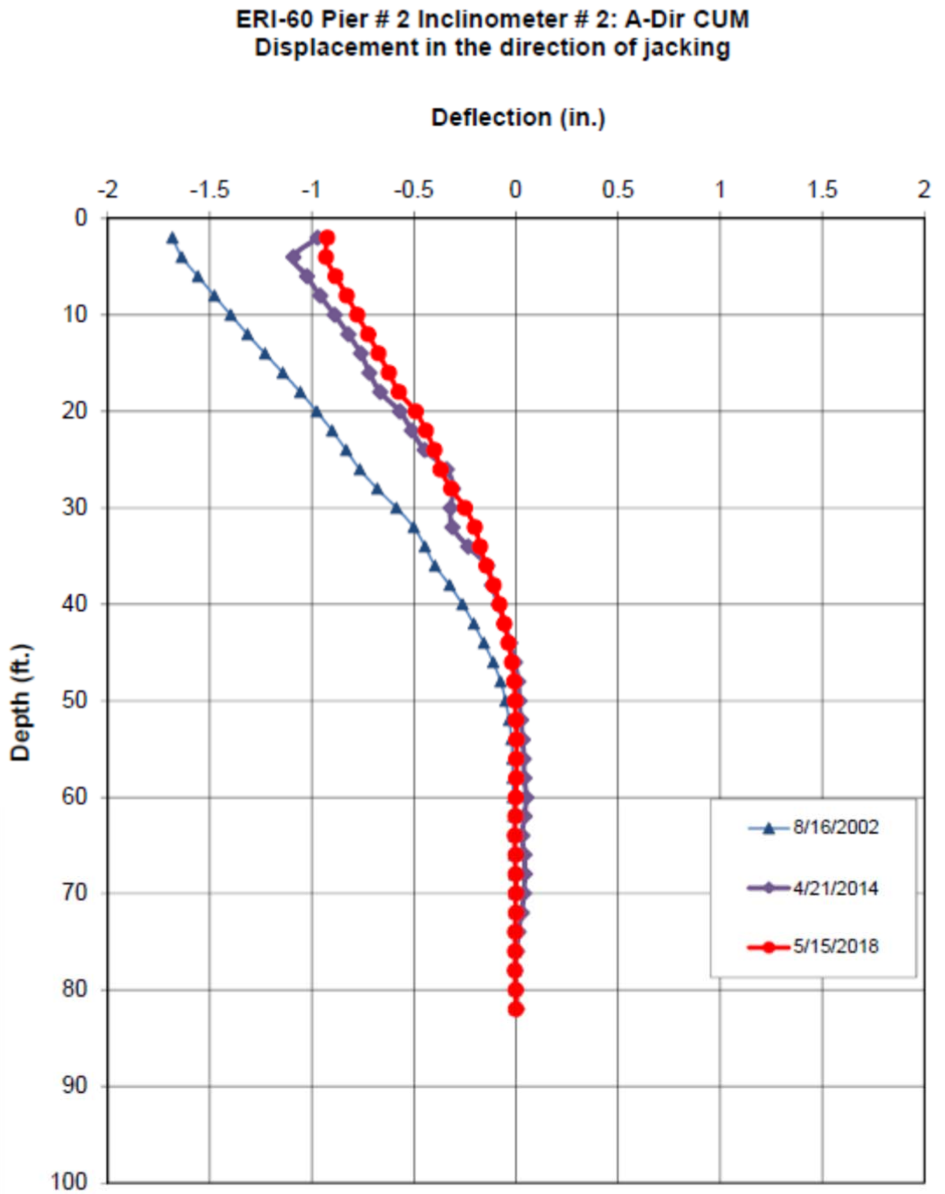

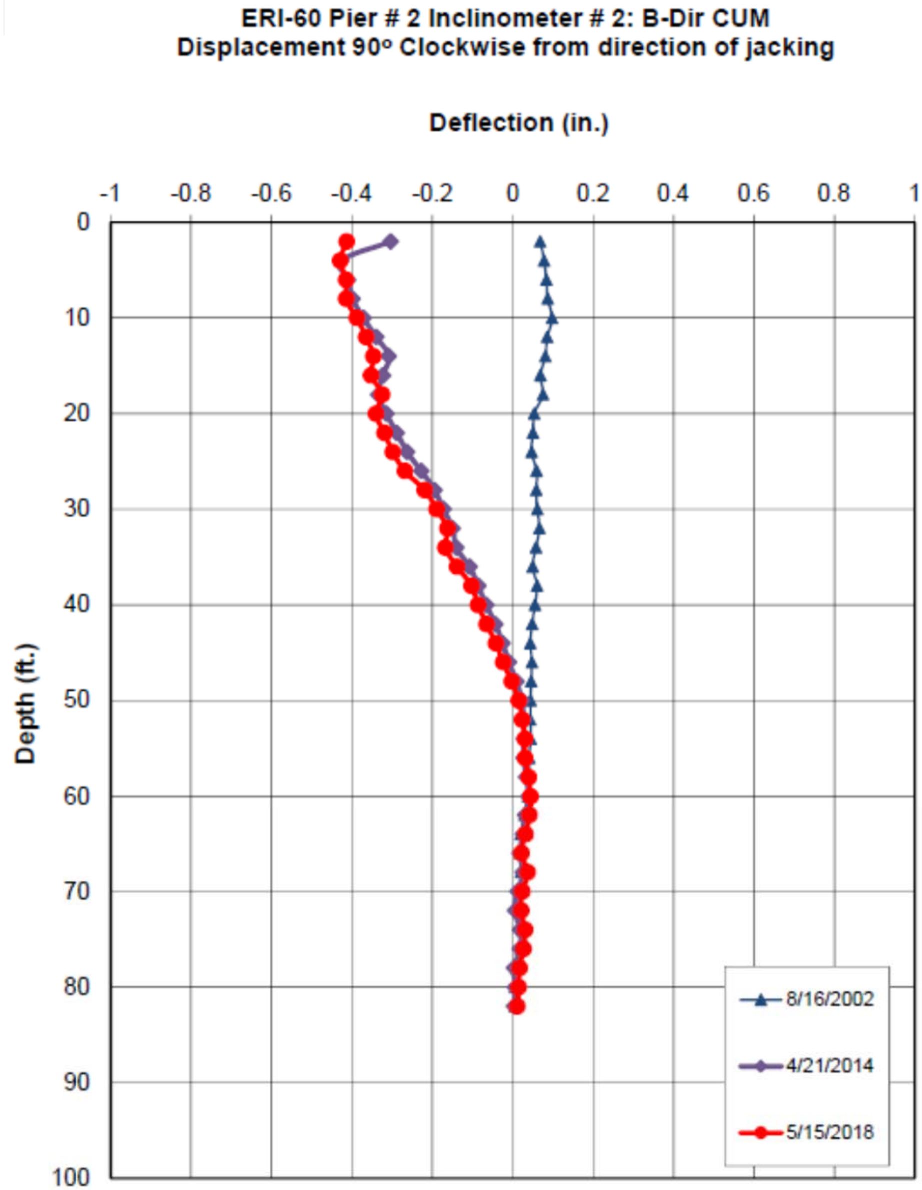

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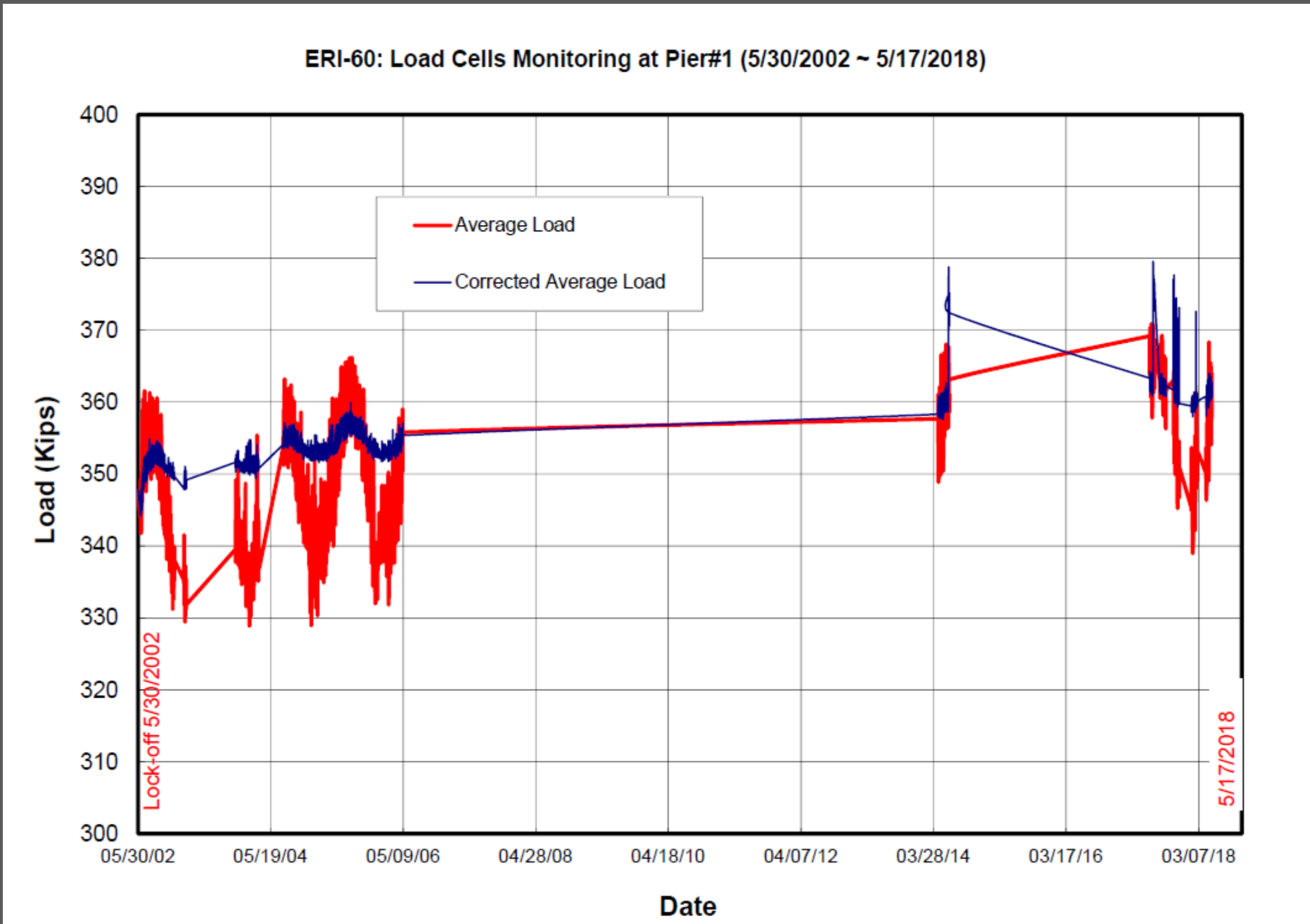
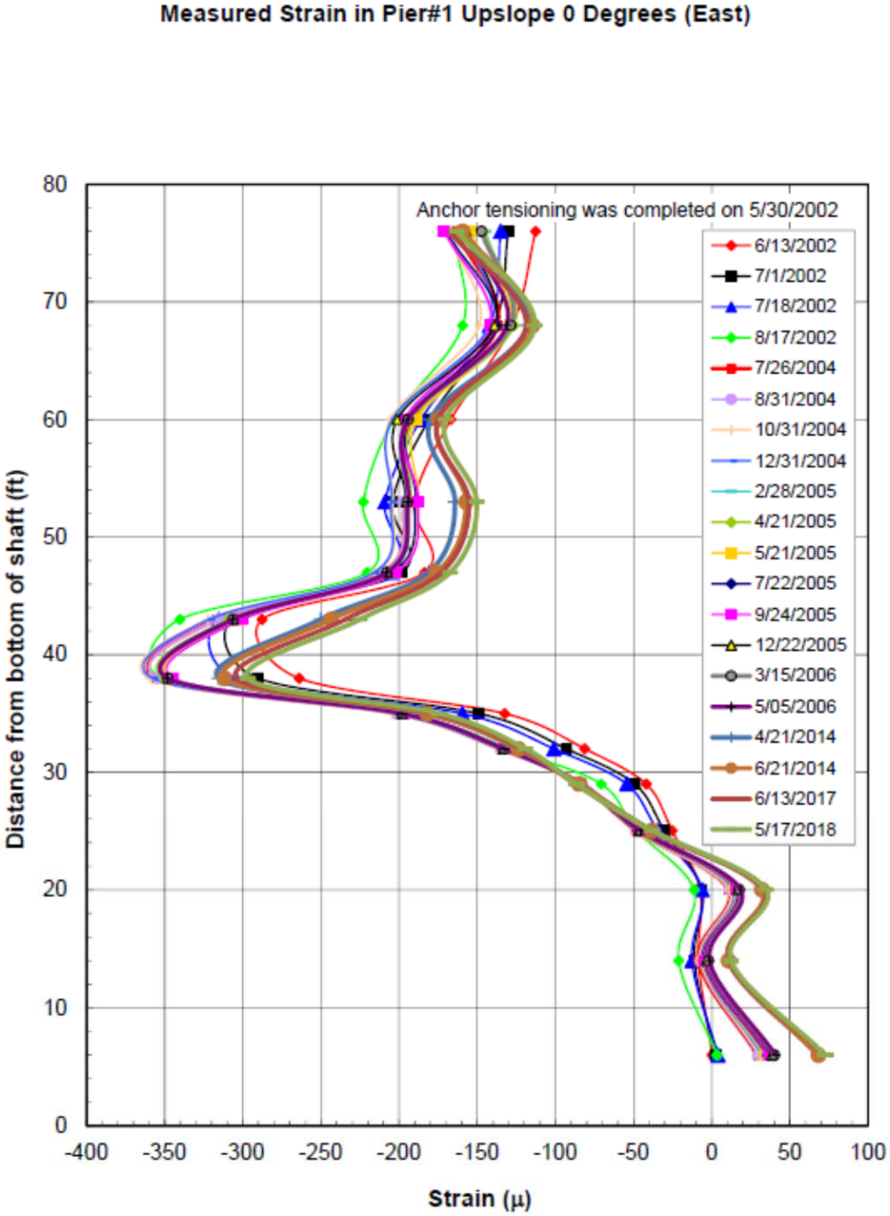
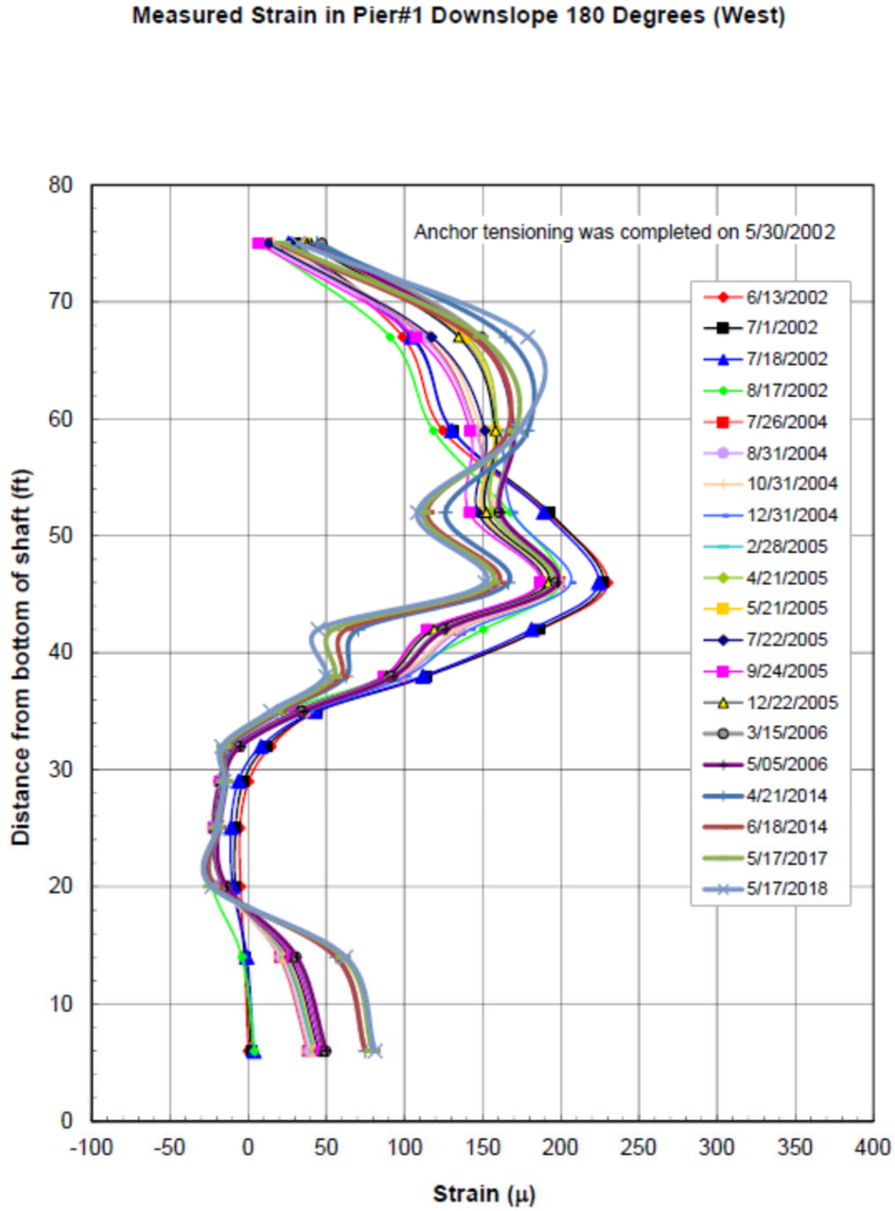

ERI-60: Load Cells Monitoring at Pier#1 (5/30/2002 ~ 5/17/2018)
Load (Kips)
400
390
380
370
360
350
340
330
320
310
300
Average Load
Corrected Average Load
Lock-off 5/30/2002
5/17/2018
05/30/02
05/19/04
05/09/06
04/28/08
04/18/10
04/07/12
03/28/14
03/17/16
03/07/18
Date





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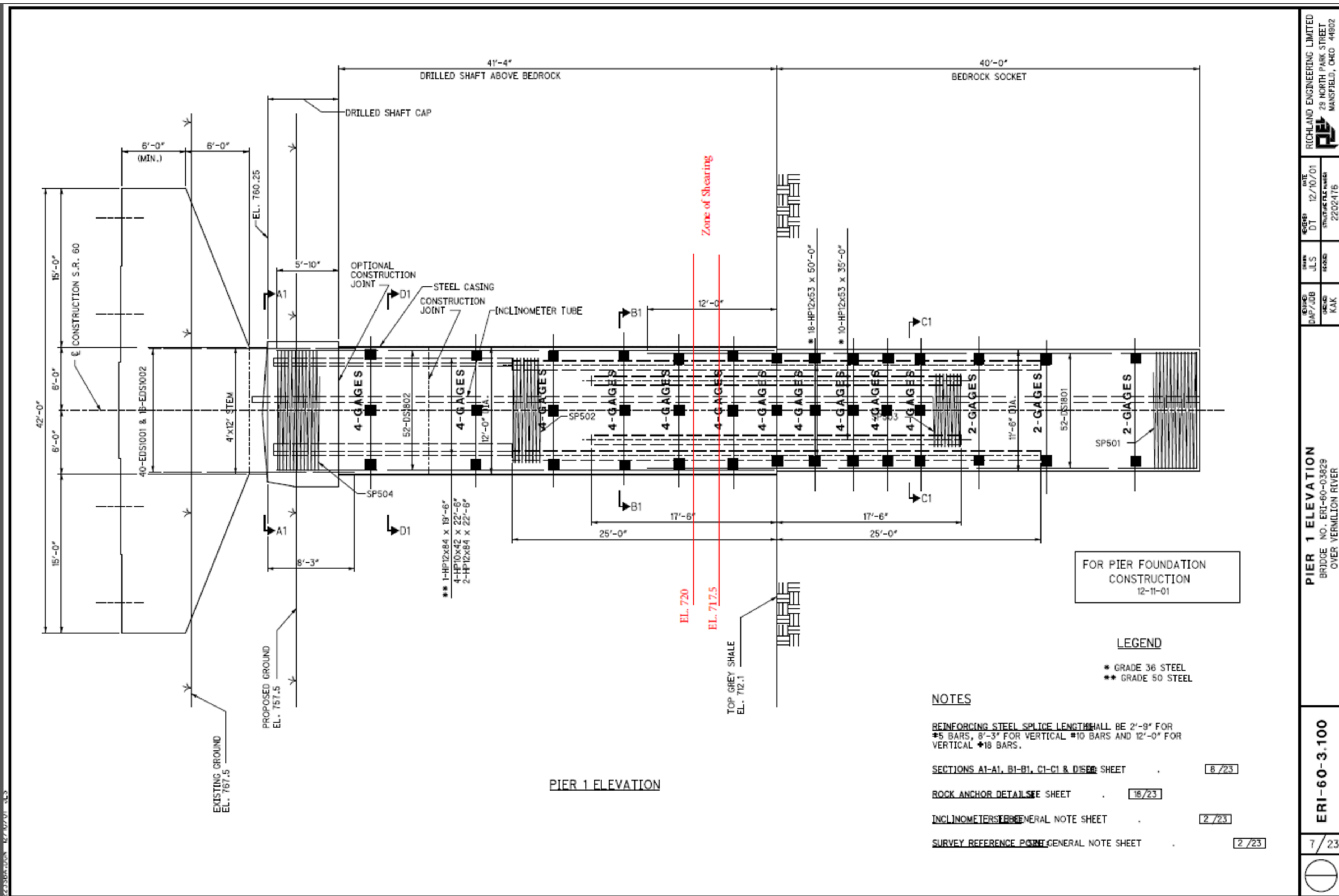

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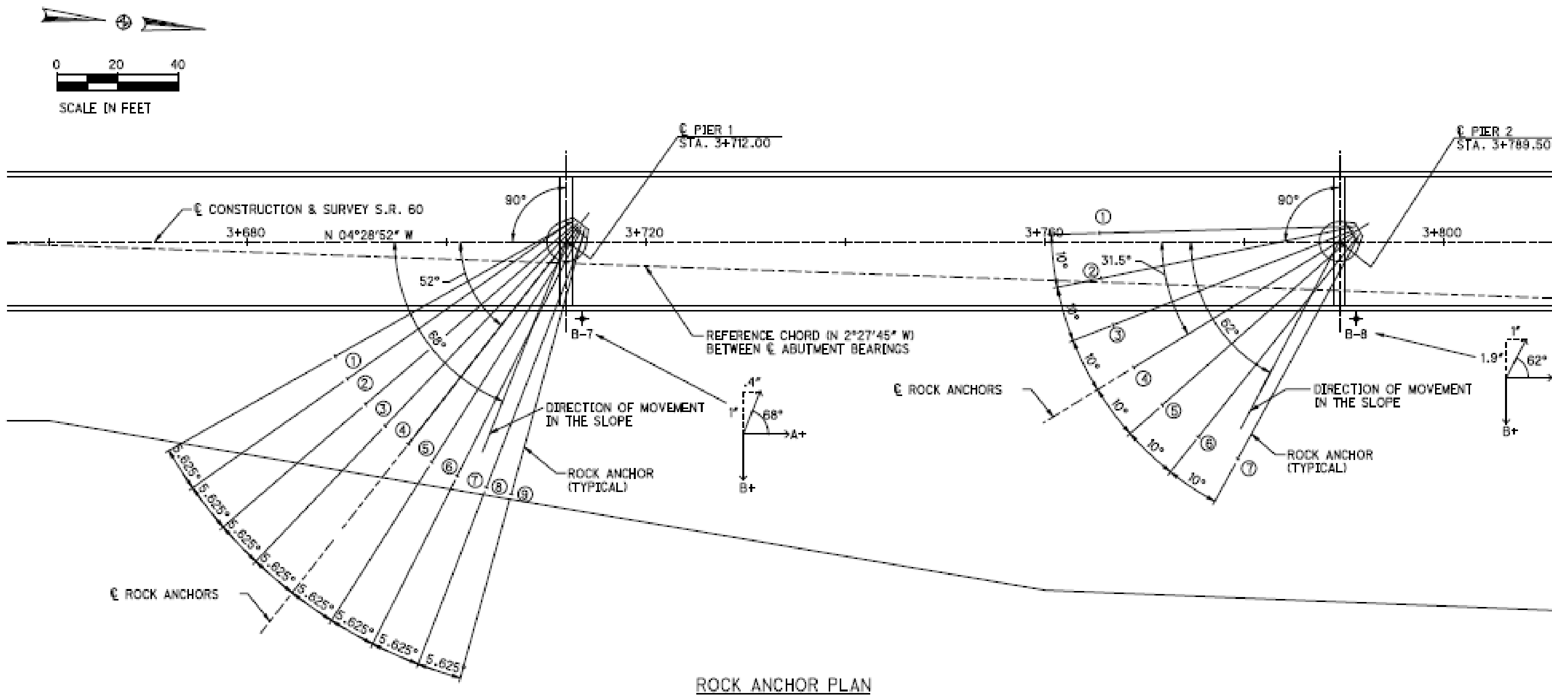
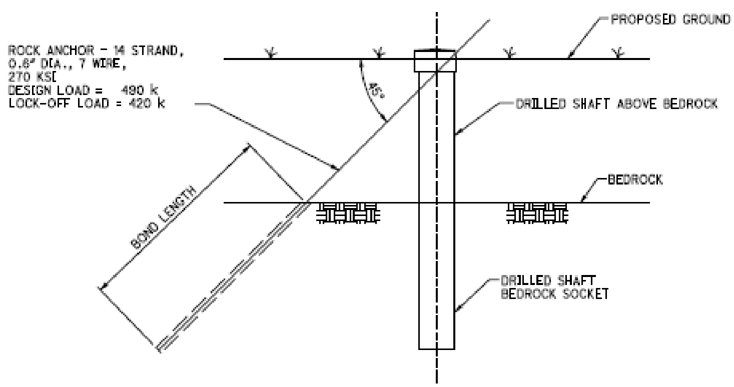


ROCK ANCHOR PLAN



ROCK ANCHOR SCHEMATIC

ENGINEERS SEAL:

SIGNED:

DATE:

FOR PIER FOUNDATION
CONSTRUCTION
12-11-01

Conclusions

- The instrumentation and monitoring added a valuable input in understanding the behavior of the piers and slope during construction and over the 16 years of monitoring.
- The deflection and strain build up is still going on as shown in the time plots.
- The monitoring is helping ODOT decide on the status of the structure and how safe it is.

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Thank you

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