TECHNICAL MEMORANDUM

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Kennedy Bridge - Summary of Pier 6 Movement Records

PREPARED FOR: MnDOT

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File

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DATE: May 16 2013

PROJECT NUMBER: 469027

Introduction

Bridge No. 9090, known as the Kennedy Bridge, carries U.S. Trunk Highway 2 across the Red River of the North between East Grand Forks, Minnesota and Grand Forks, North Dakota. This technical memorandum summarizes the records of the movements of Pier 6 of the Kennedy Bridge, as provided by the Minnesota Department of Transportation (MnDOT). It also summarizes the movement of Pier 6 relative to the steel truss superstructure. The location of Pier 6 is shown in Figure 1. An overview of the structure at Pier 6 is shown in Figure 2, with key components labelled.

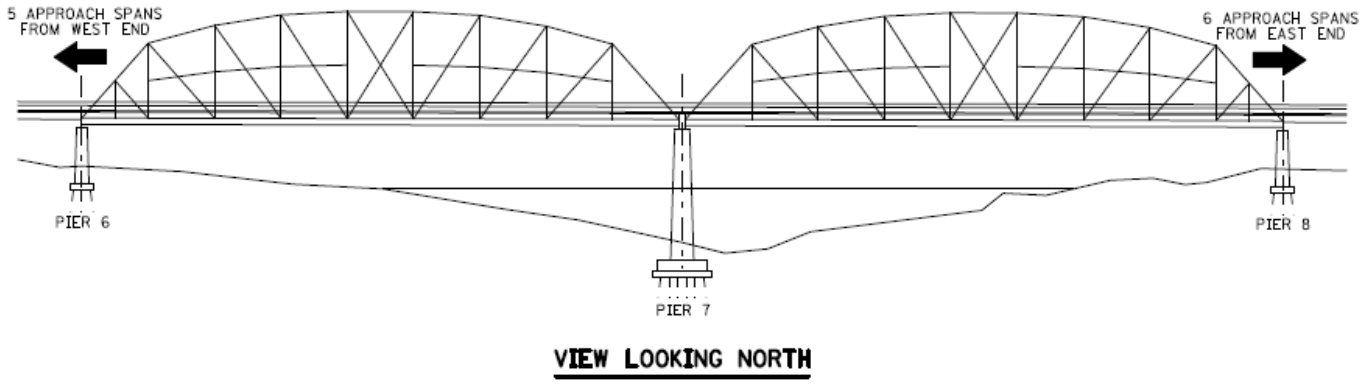


Figure 1 – Location of Pier 6

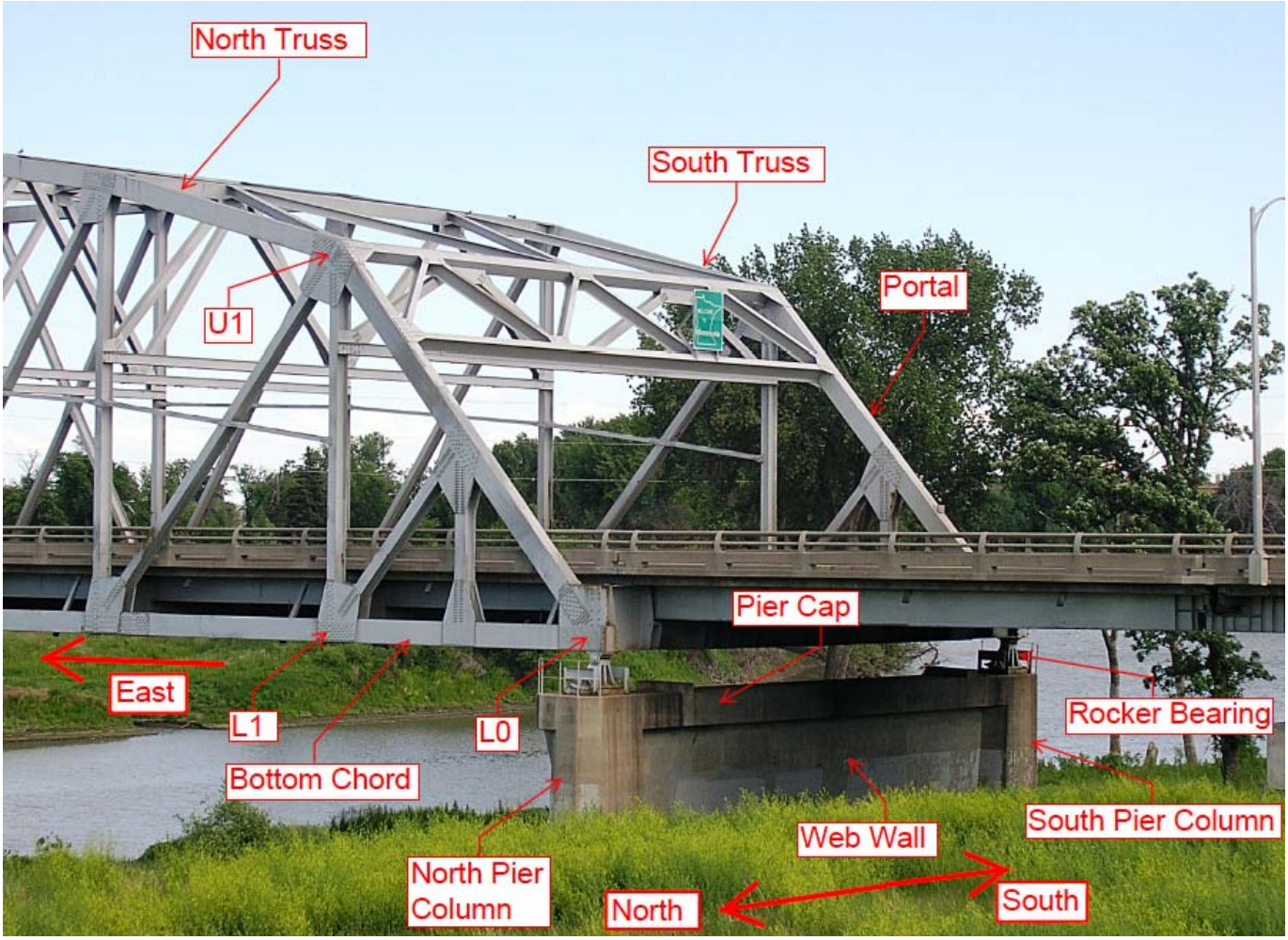


Figure 2 – Structure and Pier 6 overview. Photo taken from ND side of river, looking southeast

Movement Records

Movement records available from MnDOT addresses of three separate movements (provided in the Appendices). These documents include various field measurements related to bearing, pier and ground movement:

Log of Bearing Tilt. (See Appendix A) This document includes a log of the tilt of the bearings out of plumb that translates into top of pier movement. The measurements begin 10 September 1997 and extend through 24 October 2012. Adjustments to the rocker bases and the attachment of the bearings to the truss chord are noted along with the tilt measurements.

MnDOT records identify the bearing movement as “tilt.” The value recorded is the horizontal offset of the top of the rocker from a plumb position, rather than an angular measurement.

In addition to the rocker tilt measurements, this information contains distances from Bent 5 to Pier 6 recorded periodically between 23 September 2010 and 17 July 2012, and measurements of the bow in the wall that connects the north and south pier columns.

Pier 6 Measurements. (See Appendix B) This consists of sketches of the existing configuration of Pier 6 from field measurements as of 16 July 2012. Measurements noted include tilt of the pier, location of rocker bases on the pier cap, sketch of the rocker bearing heel measurements, log of rocker bearing tilt through the July measurements, and photos.

Slope Inclinometer Results. (See Appendix C) This document contains summaries of readings from two different slope inclinometers placed close to the south end of Pier 6. Readings cover the time periods from 3 June 2004 to 23 November 2009 (Inclinometer #1) and from 12 July 2010 through 2 May 2012 (Inclinometer #3). No readings were obtained from Inclinometer #2.

Slope inclinometer readings provide incremental and cumulative movements in two axes. Readings extend to a depth of 60 feet below the existing ground surface.

Movements not documented. All structure measurements document movement parallel to the centerline of the truss spans. No structure measurements address movement normal to the bridge. No measurements document vertical movement of Pier 6.

Discussion of Pier Movement

Initial Conditions

The initial conditions are those at the date of construction. The design drawings do not identify the location of the Pier 6 rocker bearing with respect to the pier cap and the columns that make up Pier 6. MnDOT field observations and measurements (See Figure 6) indicate that the centers of the bearings were constructed 8 inches east (toward the river) of the center of Pier 6.

Design drawings of the pier are reproduced in Figure 3. These drawings show a 5-foot-wide pier cap centered above the pier columns and the pier footing. A 2-foot-wide corbel is shown in the east side (towards the river); this corbel is believed to be provided to allow working room for jacking the truss and adjusting the bearings.

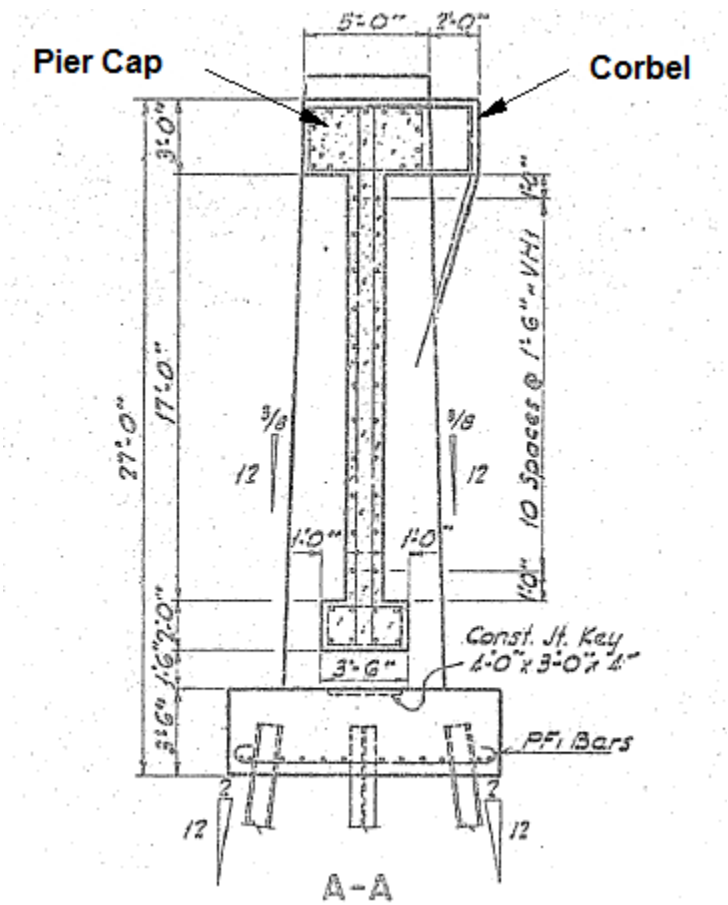


Figure 3 – Section Through Pier 6

The rocker bearing is a fabricated steel element with a cylindrical bottom surface that bears on a 5 ¾ inch thick by 36 inch wide by 60 inch long plate. A series of four pintles attached to the plate engage holes in the bottom of the rocker, preventing the rocker from translating longitudinally or transversely relative to the plate. The rocker and plate drawings are reproduced in Figure 4.

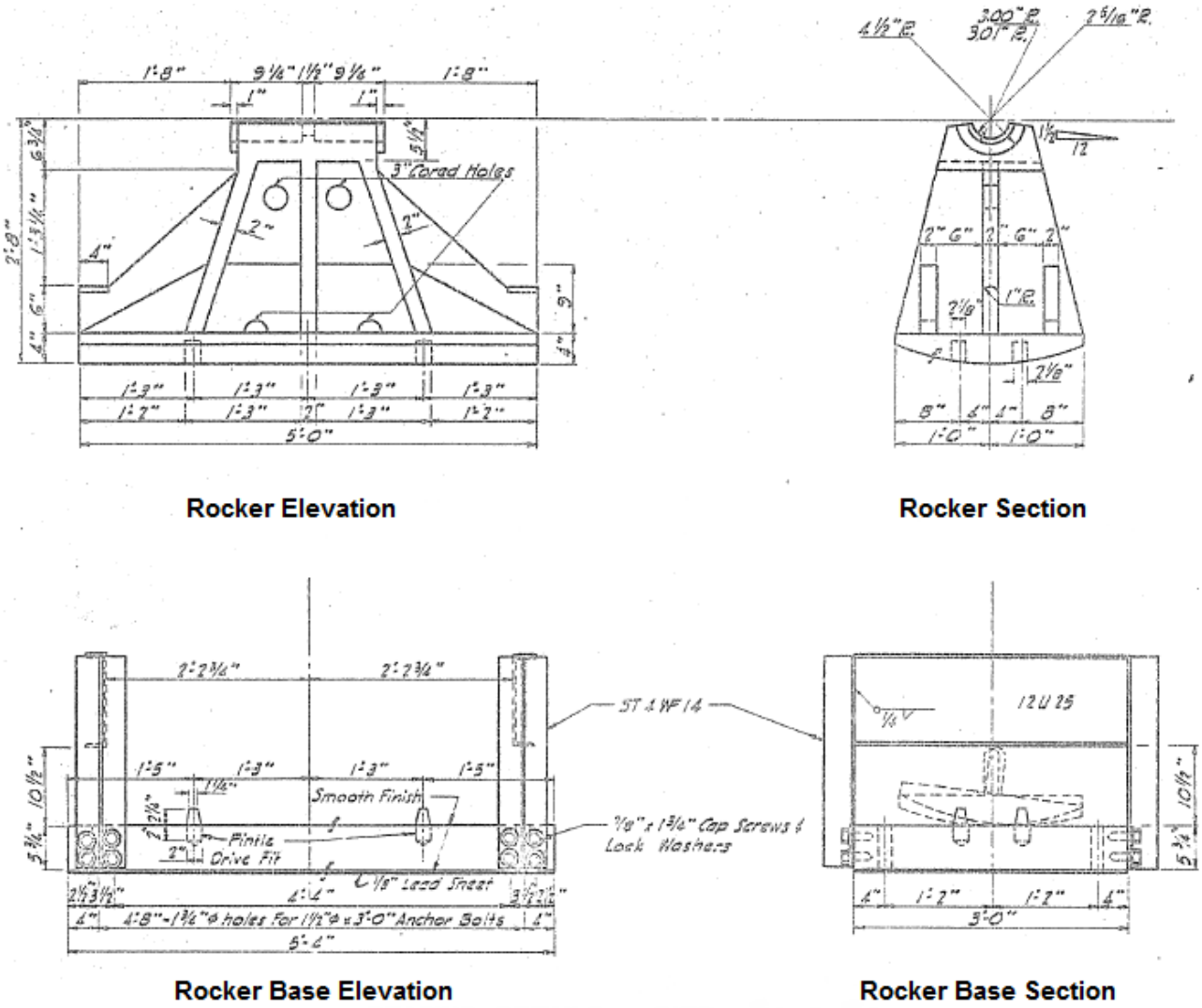


Figure 4 – Rocker and Rocker Base Detail

Bearing Movement

Variability of Bearing Movement Records

Examination of the records of the tilt of the north rocker bearing and the south rocker bearing at Pier 6 discloses that the tilt both increases and decreases between consecutive measurements. This can result from seasonal temperature variations that affect the length of the steel truss. A change in the temperature of the truss of 50 degrees F would result in a bearing movement of just over 1 inch.

The air temperature was recorded with each movement record. As it takes time for the bridge to respond to changes in air temperature, however, it is necessary to consider not only the recorded temperature but also the season in which the measurement was made. This allows judgment of whether the bridge may have been consistently warm or consistently cool long enough to have responded to the air temperature.

Variations in soil conditions that allow the pier to move both towards and away from the Red River may also affect the rocker tilt, although the slope inclinometer readings do not support movements of the soil mass away from the river.

Given the variability of the readings, it is prudent to evaluate trends in rocker bearing tilt rather than relying on specific measurements. Trends may be more revealing than individual year-to-year measurements.

First Bearing Movement Records

The first movement record consists of measurement of tilt of the rocker bearings on 10 September 1997. A note is included stating that a rocker base had been moved 5 inches prior to 1997. This note is reproduced in Figure 5; the pertinent statement is highlighted in a red box. The direction of the move was not noted, but is assumed to be west (away from the river) and from field measurements of 2012 (Figure 5) this adjustment was made to both bearing plates.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Bridge # 9090 Rocker Measurements												
2	Tilt of Rocker from Plumb												
3													
4			Location										
5	Date	Temp, ^{0}F	NE	Dir	SE	Dir	NW	Dir	SW	Dir	Total Movement	Increment	
6												Prior move approx 5 inches.	
7	9/10/1997	80	3.13	E	2.13	E	3.63	W	7.50	W	0.00		
8	6/10/1998	61	2.25	E	1.94	E	2.81	W	7.50	W	0.00		
9	5/24/1999	55	2.25	E	1.63	E	2.75	W	3.75	W	9.75	moved baseplate 6 inches	
10	7/25/2000	80	2.75	E	1.88	E	3.38	W	4.38	W	10.38		

Figure 5 – Note identifying rocker base move.

A second bearing adjustment was recorded on 24 May 1999. This adjustment consisted of relocating the rocker base 6 inches. Based on the field measurements of 2012 (Figure 5), this is understood to refer only to the bearing plate for the south side of the bridge.

In June of 1998, the south rocker bearing was tilted 7 ½ inches, with the top of the bearing west of the bottom of the bearing. After relocating the south bearing plate in 1999, the south rocker bearing remained tilted 3 ¾”. This implies that the south side of the pier moved eastward relative to the truss approximately 2 1/4” between 1998 and 1999.

Later Bearing Movement Records

After the bearing plate relocation in 1999, the tilt of the south rocker bearing continued to increase. The tilt of the north rocker bearing remained essentially constant.

The top of the south rocker bearing was relocated eastward 7 inches along the truss bottom chord in July of 2004. This resulted in a tilt of the rocker bearing of 1 3/8 inches, oriented with the top of the rocker west of the bottom of the rocker. This implies that the top of the pier moved relative to the steel truss approximately 2 inches between the May 2003 measurement and the July 2004 bearing adjustment.

Latest Bearing Movement Records

After the bearing relocation in July of 2004, the tilt of the south rocker bearing continued to increase. The tilt of the north rocker appears to have increased by a much smaller amount than did the tilt of the north rocker.

The top of both the north rocker and the south rocker were moved eastward 7 inches along the truss chord in July of 2012. After this adjustment, the north rocker bearing had been adjusted a total of 7 inches and the south rocker bearing had been adjusted a total of 14 inches.

After the July 2012 bearing adjustments, the south rocker bearing was essentially plumb. The north rocker bearing was tilted with the top of the bearing east of the bottom of the bearing.

The south rocker bearing was tilted 6 ¾ inches to the west two months prior to the adjustment. The 7 inch adjustment brought the rocker close to plumb.

The north rocker bearing was 3 inches to 4 inches out of plumb prior to the bearing adjustment, and was 1 $^{3}/_{8}$ inches out of plumb in the opposite direction after the bearing adjustment.

Current Bearing Conditions

The most recent bearing measurements were obtained in October of 2012. Those measurements show the north rocker bearing tilted 2 inches to the east and the south rocker bearing as plumb. These readings are within the operating range of the bearings.

Figure 6 shows the field measurements locating the rocker bases on the pier cap. This diagram is copied from the MnDOT field notes. Figure 7 contains a photograph of the south rocker bearing, with the rocker base movement noted.

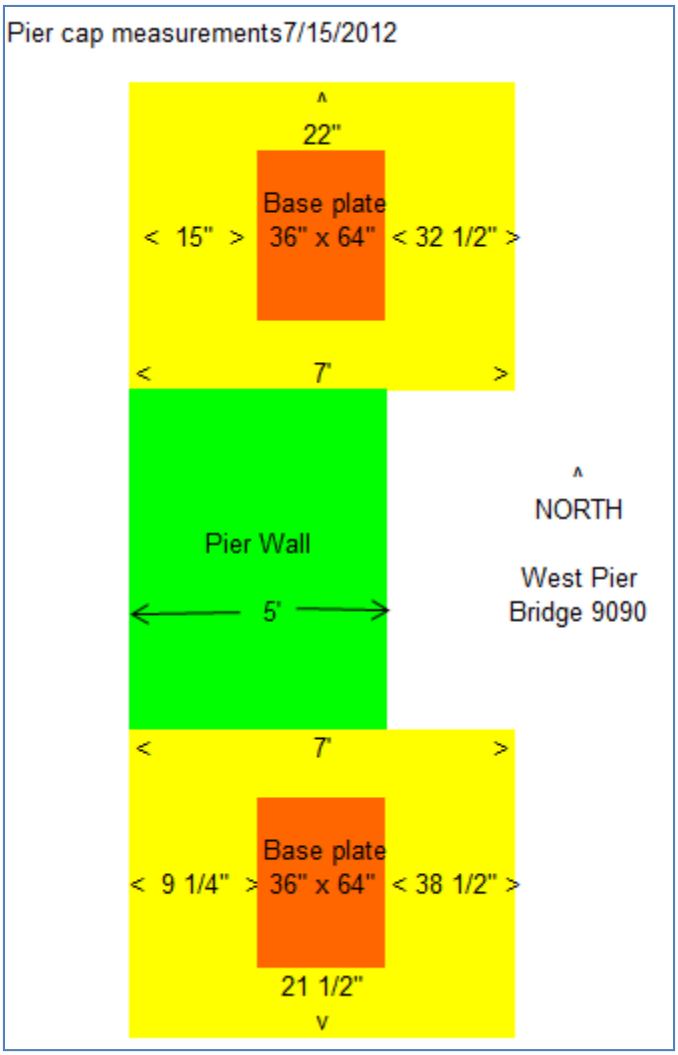


Figure 6 – Field Measurements of Pier Cap

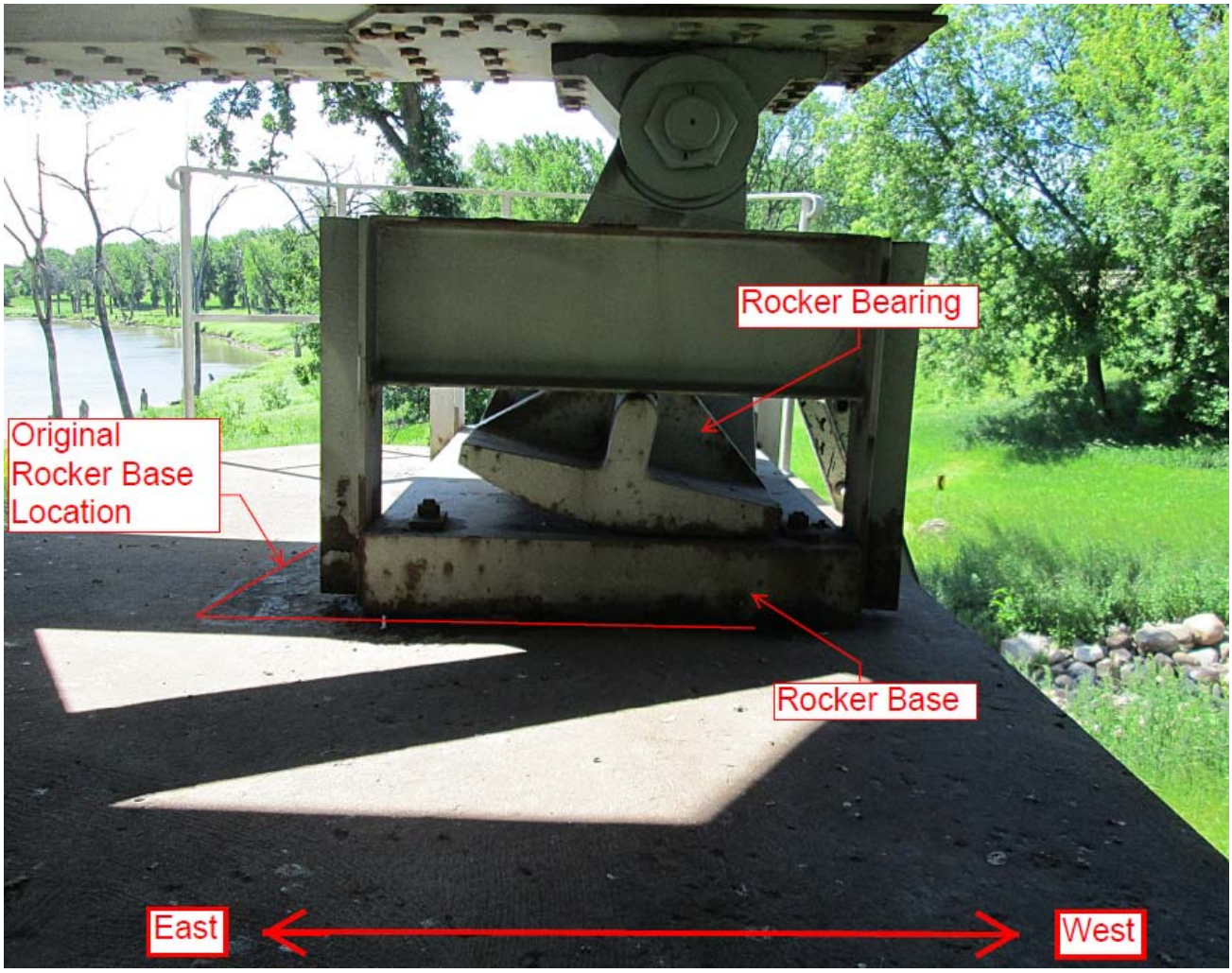


Figure 7 – South Rocker Bearing, Pier 6, looking south along top of pier

Rate of Bearing Movement

The rate of movement of the rocker bearing is relatively uniform over the time in which MnDOT has been monitoring the movement of the bearing. Bearing adjustments have been made prior to 1997, in 1999, in 2004, and in 2012. Adjustment of the bearings has been infrequent and irregular, and there is insufficient information to determine a trend in bearing adjustments.

Bearing Movement Diagram

As an aid to interpreting the movement of the rockers and the rocker bases over time, a schematic diagram of the rockers, the rocker bases, and the center of Pier 6 relative to the end of the truss is presented in Figure 8. For each of five separate dates, an elevation diagram of each bearing is shown. A plan diagram of the two bearings is also shown.

The information is presented as stick diagrams for clarity, as a scaled image of the structure would make it difficult to see the movement of the various elements. Elements are labelled in one elevation diagram and in one plan diagram.

The first diagram shows the bridge as constructed. The rockers are plumb, and the workpoint at the end of the truss is centered over the rocker bases. The rocker bases are aligned with the center of bearing on the concrete pier. The center of the pier is aligned with the end of the truss.

The second diagram represents the first bearing measurement, dated 9/10/1997. The rocker bases at both north and south bearings have been moved approximately 5 inches west on the top of the pier. The north rocker is inclined such that the top of the rocker is 3.63 inches west of the center of the rocker base. The south rocker is inclined with the top of the rocker 7.5 inches west of the center of the rocker base. The plan diagram shows the top of the pier twisted about a vertical axis.

The third diagram represents the bearings on 5/24/1999. The rocker base at both north bearing is still 5 inches west on the top of the pier, but the south rocker base has been moved an additional 6 inches westward for a total movement of 11 inches. The north rocker is inclined such that the top of the rocker is 2.75 inches west of the center of the rocker base. The south rocker is inclined with the top of the rocker 3.75 inches west of the center of the rocker base. The plan diagram shows the top of the pier twisted further about a vertical axis.

The fourth diagram represents the bearings on 7/7/2004. The rocker base at both north bearing is still 5 inches west on the top of the pier and the south rocker base is still 11 inches westward. The north rocker is inclined such that the top of the rocker is 3.25 inches west of the center of the rocker base. The south rocker has now been moved 7 inches along the bottom chord of the truss, and is inclined with the top of the rocker 1.38 inches west of the center of the rocker base. The plan diagram shows the top of the pier twisted further about a vertical axis.

The last diagram in the series represents the bearings on 7/17/2012. The rocker base at both north bearing is still 5 inches west on the top of the pier and the south rocker base is still 11 inches westward. The north rocker has been moved 7 inches along the top chord, and is inclined such that the top of the rocker is 1.38 inches east of the center of the rocker base. The south rocker has now been moved an additional 7 inches along the bottom chord of the truss for a total of 14 inches, and is inclined with the top of the rocker 0.18 inches west of the center of the rocker base. The plan diagram shows the top of the pier twisted further about a vertical axis.

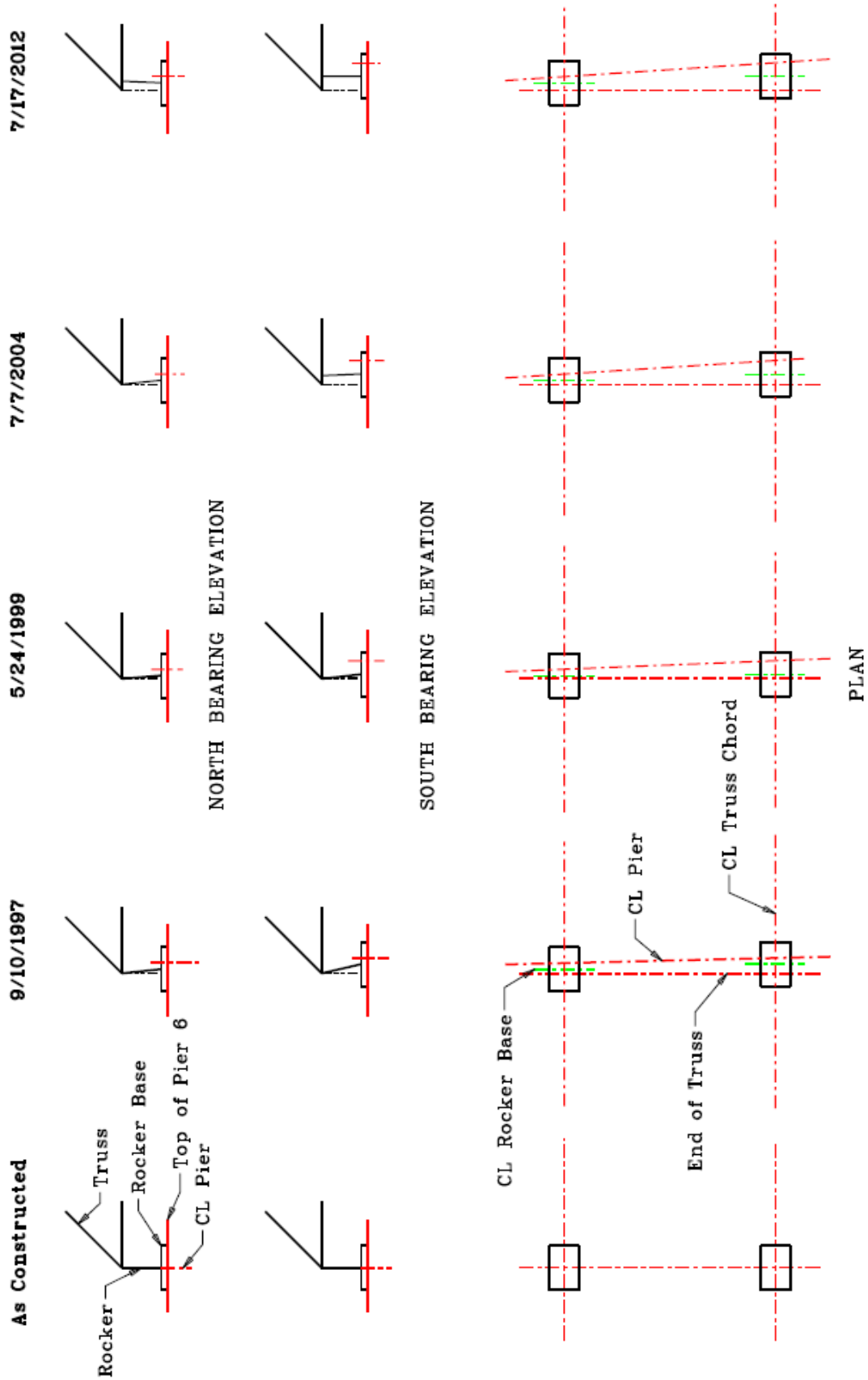


Figure 8 – Schematic of Bearing Movement over time

Pier Displacement Records

Bent 5 to Pier 6 Distance

Periodic measurements were made of the distance between Bent 5 and Pier 6, beginning in September of 2010 and extending to October 2012. These measurements are reproduced in Appendix B. Locations of measurements are not indicated in the movement tables.

The distance between Bent 5 and Pier 6 varies over time. The distance increases and decreases, as shown in the plot in Figure 9. This plot shows only the variation in distance, and is created by subtracting the initial value (the dimension on 9/23/2010) from the dimensions recorded by MnDOT. For the north measurements the value 72.35 is subtracted; 63.35 is subtracted from the center measurements, and 68.95 is subtracted from south measurements. This technique accentuates the differences between measurements.

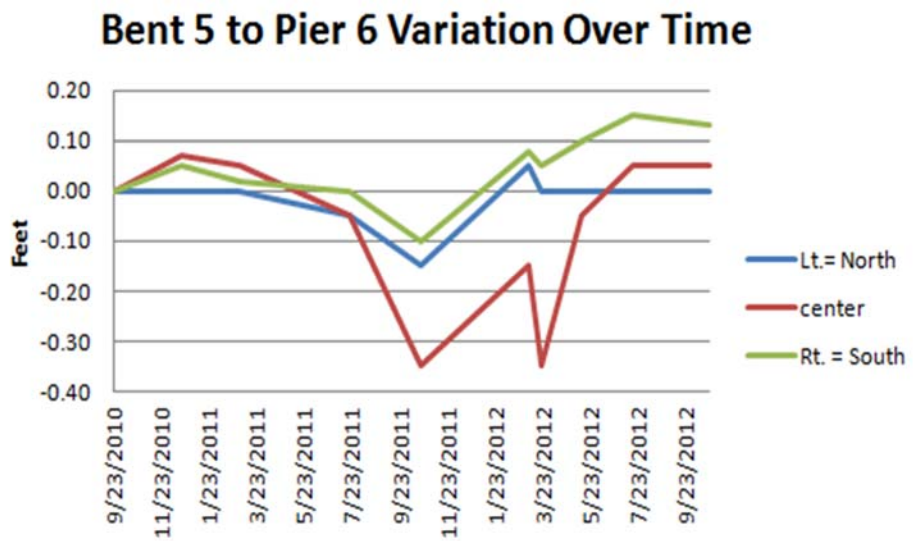


Figure 9 – Change in Distance between Bent 5 and Pier 6

A pertinent observation is that the distance between Bent 5 and Pier 6 both increases and decreases over time. There are some similarities in the movement curves; for example, the distance is a minimum for all three locations at the October 2011 measurement.

A second pertinent observation is that the distance between Bent 5 and Pier 6 at the north side of the bridge is more than 3 feet larger than the corresponding distance at the south side of the bridge. This difference is shown in the figure “Triangulation” in Appendix B as the difference between Series 2 and Series 8. This is the opposite of what is expected based on tilting of the rockers and tilting of the pier. This may be accounted for by differences in location of the measurements, but without specific information regarding the location of the measurements the significance of this difference cannot be estimated.

Bow in Pier 6 Wall

The distortion of the center wall between the north and south columns of Pier 6 was measured periodically, beginning in September of 2010 and extending to October 2012. Measurements are assumed to be in inches, measured from a horizontal stringline parallel to the concrete wall.

The distortion varies from 5.5 inches to 5.75 inches, and is observed to both increase and decrease. This variation in distortion of the center wall is not likely to be significant.

Pier Tilt

Detailed measurements of the tilt of Pier 6 were collected in July of 2012. Field notes for this measurement are contained in Appendix B.

The south column at Pier 6 is tilted at a slope of ½ inch horizontal per foot vertical. The top of the pier is further west (away from the Red River) than is the footing.

The north column at Pier 6 is tilted at a slope of $^{1}/_{8}$ inch horizontal per foot vertical. The top of the pier is further west (away from the Red River) than is the footing.

The pier height is 27 feet. Using the tilt as measured in July of 2012, the footing at the south of Pier 6 has moved approximately 13.5 inches relative to the top of the pier. The footing at the north of Pier 6 has moved approximately 3.4 inches relative to the top of the pier.

The measurements of rocker bearing tilt, which are described above, indicate that the top of Pier 6 is moving eastward relative to the steel truss. The pier tilt indicates that the pier footing is moving eastward relative to the top if the pier. This means that the movement at the rocker bearing and the footing displacement calculated based on the pier tilt are in the same direction.

Combining the rocker movement and the pier tilt, the footing under the north side of Pier 6 appears to have moved approximately 13.5 inches eastward relative to the steel truss above. The footing under the south side appears to have moved approximately 38.5 inches eastward relative to the steel truss above.

Figure 10 contains a summary of the movement of Pier 6 at the south side of the pier relative to the steel truss. This figure includes the effect of adjustment of the rocker base and rocker bearing.

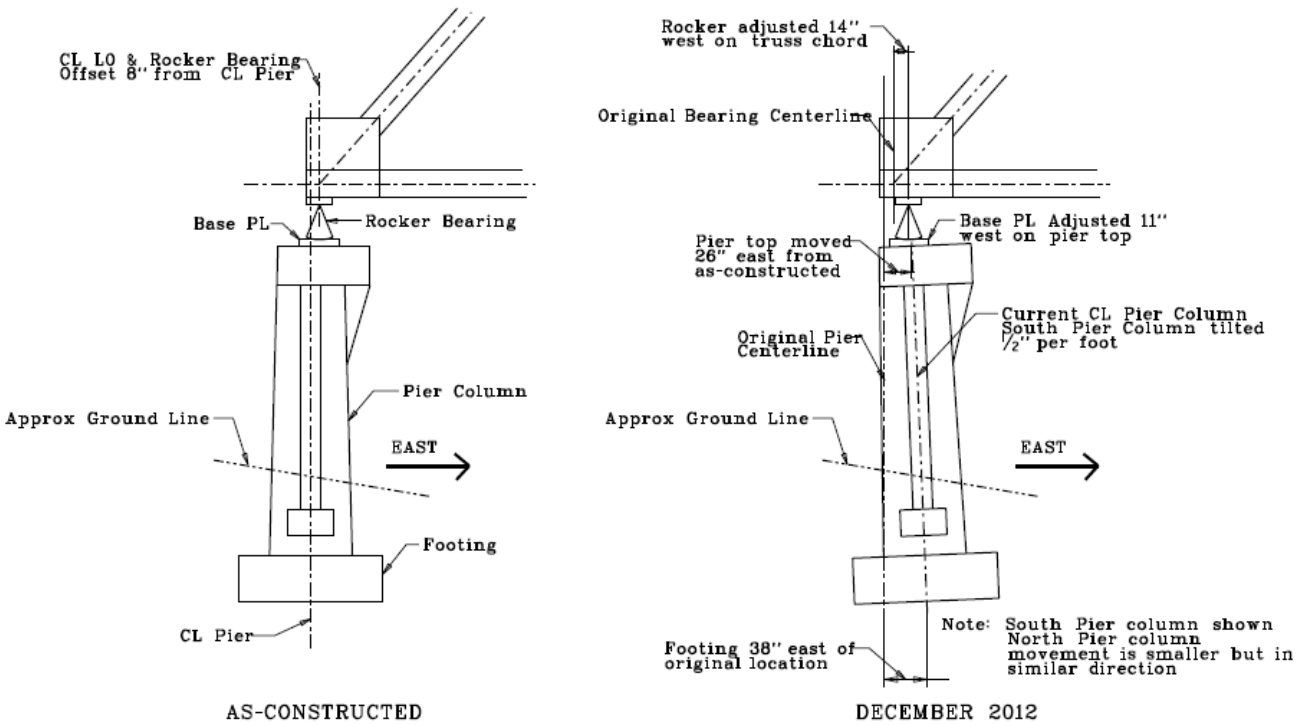


Figure 10 – Pier 6 Movement

Ground Movement Records

Three slope inclinometers were installed south of Pier 6. Records of the slope inclinometer results are shown in Appendix C. Slope inclinometer No. 1 was functional from June of 2004 through November of 2009. Slope inclinometer No. 3, installed adjacent to inclinometer No. 1, was functional from July 2010 and was still operational at the most recent reading in May of 2012.

Slope inclinometer No. 2 was distressed by buoyant forces. No valid readings were obtained from this device.

Inclinometers No. 1 and No. 3 provide readings in two orthogonal axes. The North Dakota Department of Transportation reports that the A-Axis is oriented approximately 131 degrees from true north, which is approximately 45 degrees from the longitudinal axis of the bridge. Positive movements are toward the Red River.

Both functioning inclinometers indicate a slip plane at a depth approximately 6 feet below ground surface and another slip plane approximately 27 feet below ground surface. The upper slip plane is above the pier footing, and the lower slip plane is approximately 17 feet below the pier footing. Relative displacement of the soil between the lower slip plane and the bottom of the inclinometers appears to be negligible.

Displacements in the A-Axis and the B-Axis are very similar in magnitude. The vector sum of movements in the A-Axis and the B-Axis is generally normal to the river and parallel to the longitudinal axis of the bridge.

Slope inclinometer data suggest that the ground and the bottom of Pier 6 sat the south side of the bridge have moved toward the river approximately 22 inches over the course of eight years. The movement has been fairly steady, at a little under 3 inches per year. Soil movement at a depth of 10 feet is significantly less, with a total movement of just under nine inches over the eight-year period of the movement records.

Evaluation of the slope inclinometer data presumes that the primary axes of inclinometers 1 and 3 are aligned. If this is the case, the direction of movement of the upper layer of soil (surface to a depth of approximately 6 feet) may be different than the direction of movement of the soil between depths of 6 feet and 27 feet. The difference in direction is approximately 20 degrees. If the A-axis and B-axis of inclinometers 1 and 3 are not aligned, the relative direction of movement of the two layers is inconclusive.

Appendix A – Rocker Bearing and Pier Movement

Appendix A contains summaries of rocker bearing movement, Pier 6 movement relative to Pier 5, and measurements of the bow in the web wall at Pier 6. Data was collected by MnDOT.

Page A-1 contains the rocker bearing movement measurements

Page A-2 contains distances between Piers 5 and 6, and measurements of the bow in the Pier 6 web wall.

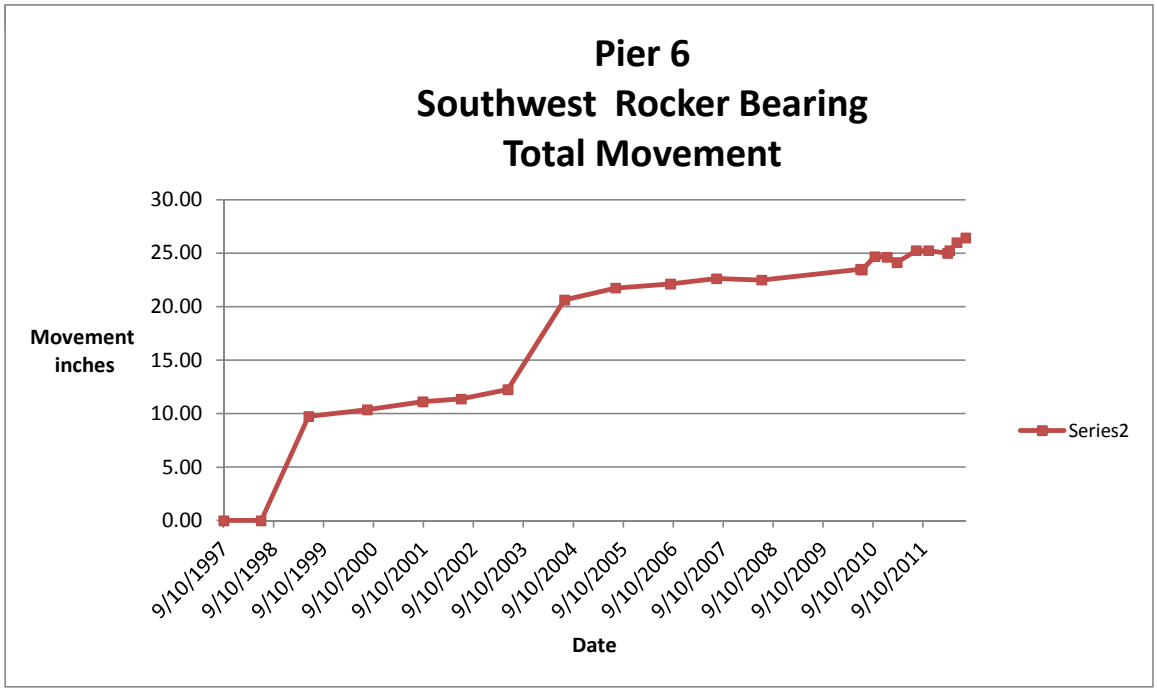
Page A-3 contains measurements of the rocker heel above the rocker base, for the northwest rocker, as taken on three dates in 2012.

The data is shown as provided by MnDOT. Page numbers were added by CH2M HILL.

Bridge # 9090 Rocker Measurements
Tilt of Rocker from Plumb

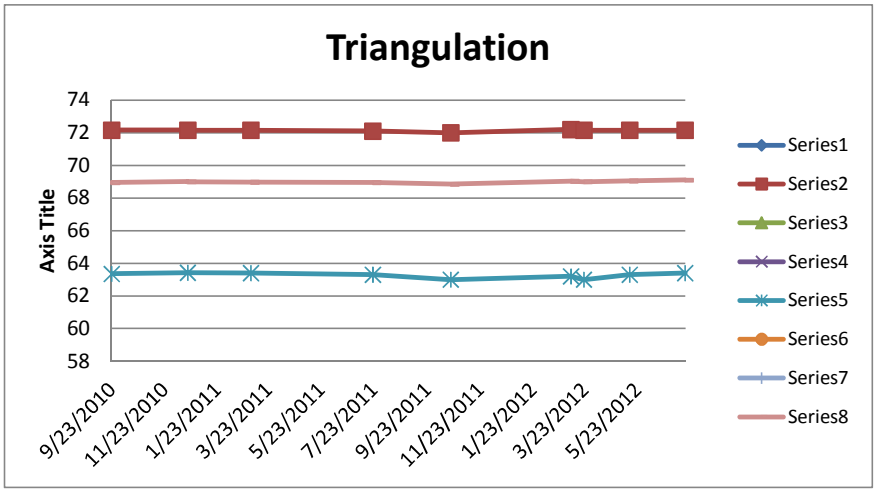
Date	Temp, ^{0}F	Location NE	Dir	SE	Dir	NW	Dir	SW	Dir	Total Movement	Increment
											Prior move approx 5 inches.
9/10/1997	80	3.13	E	2.13	E	3.63	W	7.50	W	0.00	
6/10/1998	61	2.25	E	1.94	E	2.81	W	7.50	W	0.00	
5/24/1999	55	2.25	E	1.63	E	2.75	W	3.75	W	9.75	moved baseplate 6 inches
7/25/2000	80	2.75	E	1.88	E	3.38	W	4.38	W	10.38	
9/4/2001	82	2.50	E	2.00	E	2.75	W	5.13	W	11.13	
6/12/2002	65	2.00	E	1.75	E	3.13	W	5.38	W	11.38	
5/20/2003	62	2.38	E	1.75	E	2.88	W	6.25	W	12.25	
7/7/2004	62	2.25	E	2.63	E	3.25w	W	1.38	W	20.63	Moved top of S rocker 7 inches
7/15/2005	74	2.25	E	2.00	E	3.38	W	2.50	W	21.75	
8/20/2006	80	2.50	E	1.88	E	3.25	W	2.88	W	22.13	
7/23/2007	88	2.13	E	1.75	E	1.63	W	3.38	W	22.63	
6/17/2008	75	2.13	E	1.63	E	3.375W		3.25	W	22.50	
6/22/2010	80	2.19	E	2.74	E	4.56	W	4.19	W	23.44	
6/9/2010	70					3.88	W	4.25	W	23.50	
9/23/2010	55						W	5.44	W	24.69	
12/20/2010	15						W	5.38	W	24.63	
3/3/2011	20						W	4.88	W	24.13	
7/22/2011	75					4.38	W	6.00	W	25.25	
10/20/2011	62					4.00	W	6.00	W	25.25	
3/7/2012	20					3.50	W	5.75	W	25.00	
3/22/2012	55					3.00	W	6.00	W	25.25	
5/14/2012	75						W	6.75	W	26.00	heel of rocker = 1/2 in. west / 4 7/8 in east
7/17/2012	80					1.38	E	0.18	W	26.43	Moved top of N & S rockers 7" W
10/24/2012	40					2.10	E	0.00		26.61	Oct 2012 SW rocker is plumb, but peir cap / base plate are at approx. 3.8 % grade causeing heel of rocker meas. to differ.

Note: As of 10-15-2010, the base plate had been moved approximately 11 inches, and the top of rocker approx 7 inches.



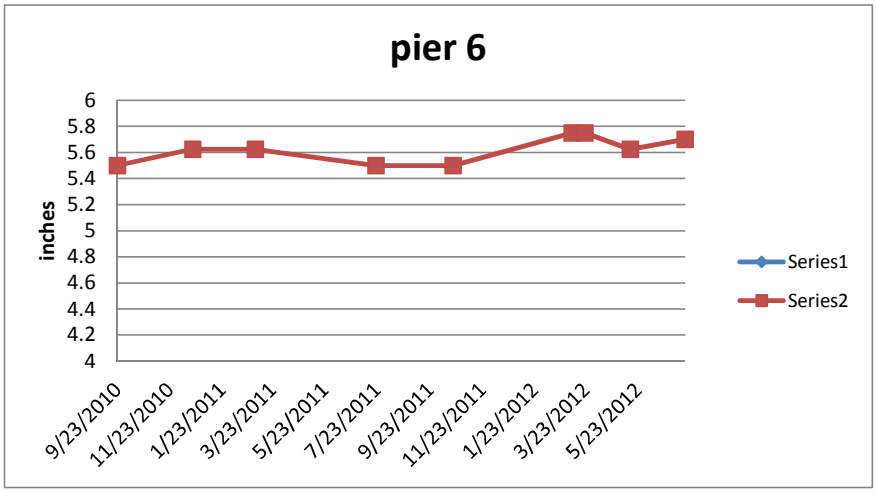
Stringline measurements from Bent 5 to Pier 6
3 measurements from Bent 5 centerwall to bottom of Pie Pier 6 3 locations Rt. Center & Lt.

	Lt.= North	center	Rt. = South
9/23/2010	72.15	63.35	68.95
12/20/2010	72.15	63.42	69.00
3/3/2011	72.15	63.4	68.97
7/22/2011	72.10	63.3	68.95
10/20/2011	72.00	63	68.85
3/7/2012	72.20	63.20	69.03
3/22/2012	72.15	63	69.00
5/14/2012	72.15	63.3	69.05
7/17/2012	72.15	63.4	69.10
10/24/2012	72.15	63.4	69.08



pier 6 meas. Bow in wall

9/23/2010	5.500
12/20/2010	5.625
3/3/2011	5.625
7/22/2011	5.500
10/20/2011	5.500
3/7/2012	5.750
3/22/2012	5.750
5/14/2012	5.625
7/17/2012	5.700
10/24/2012	5.500



N.W. rocker heel measurement in inches

	east	west
march 22 nd 2012	4.6	0.8
may 14 2012	4.25	1
Oct 24 2012	1.88	2.2

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Appendix B – Pier Movement

Appendix B contains field sketches of the tilt of Pier 6, and sketches of the measurements of the tilt of the rocker bearings, and a graphic of the location of the rocker bearings on the top of Pier 6. Three photographs of the bearing are included. Data and photos were collected by MnDOT.

Page B-1 through B-2 illustrate the tilt of Pier 6.

Page B-3 contains overall dimensions of Pier 6 as measured by MnDOT

Page B-4 illustrates the location of the rocker bases on the top of Pier 6.

Pages B-5 and B-6 contain photographs of the south end of Pier 6.

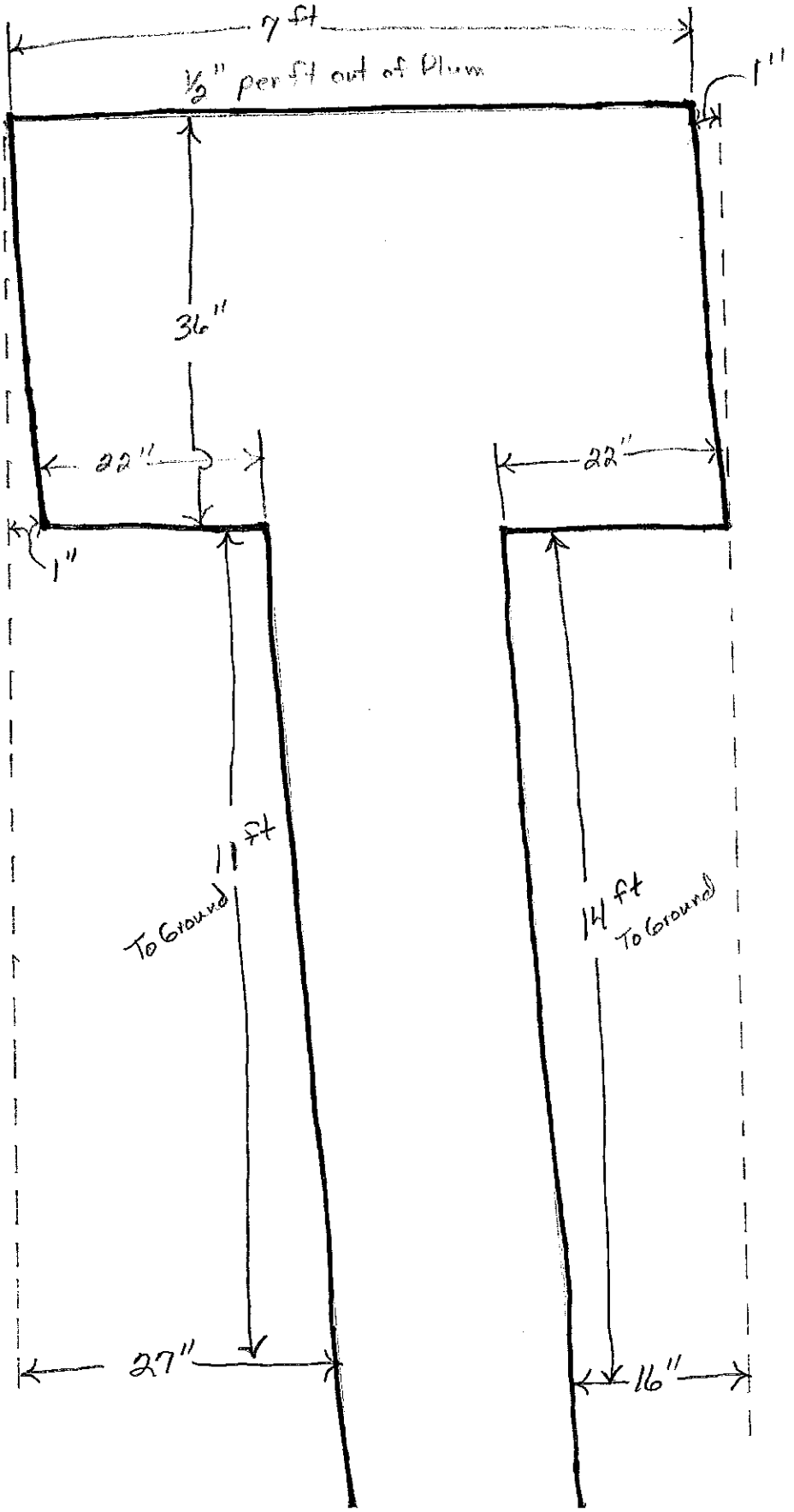
The data is shown as provided by MnDOT. Page numbers were added by CH2M HILL.

PIER 6 BR 9090
7/16/2012

FIELD MEASUREMENTS
TOM TUPPE

T2009090

South Side of Peir



MD side

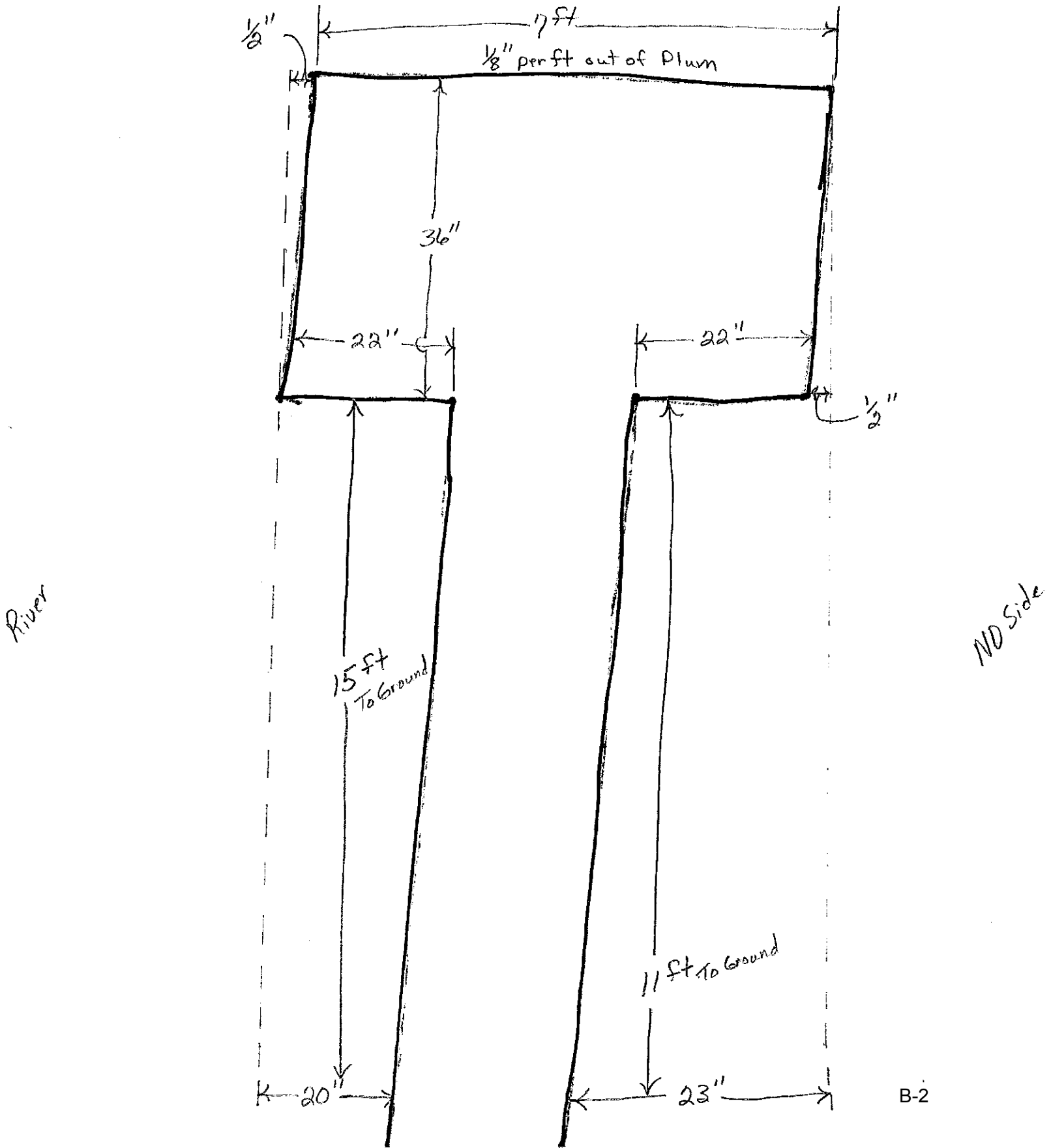
River

Pier 6
Bridge 9090
7/17/2012

FIELD MEASUREMENTS
TOM E. TUPPE

T5009090

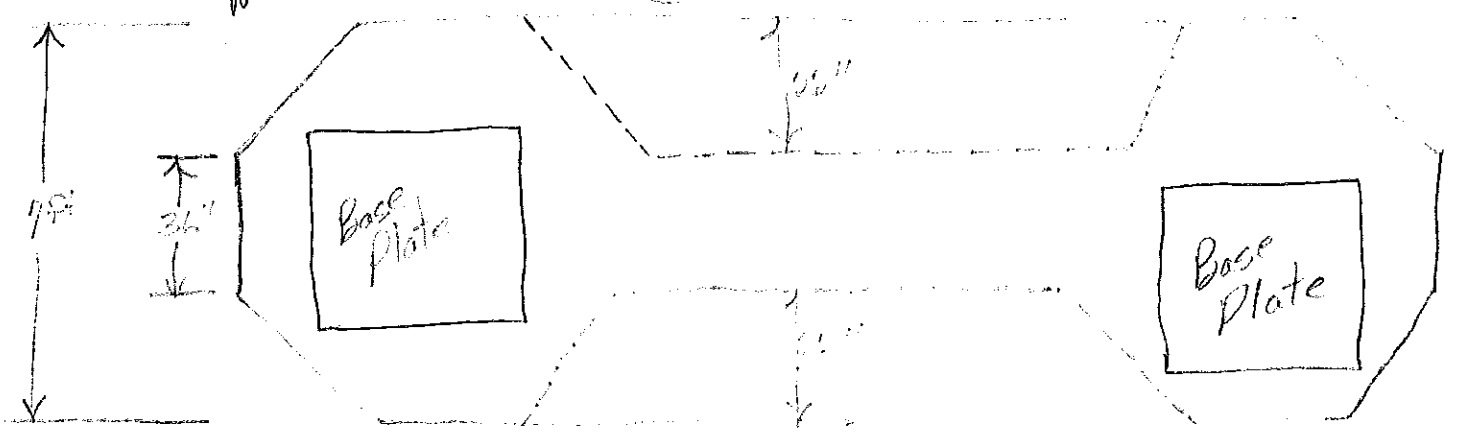
North Side of Pier

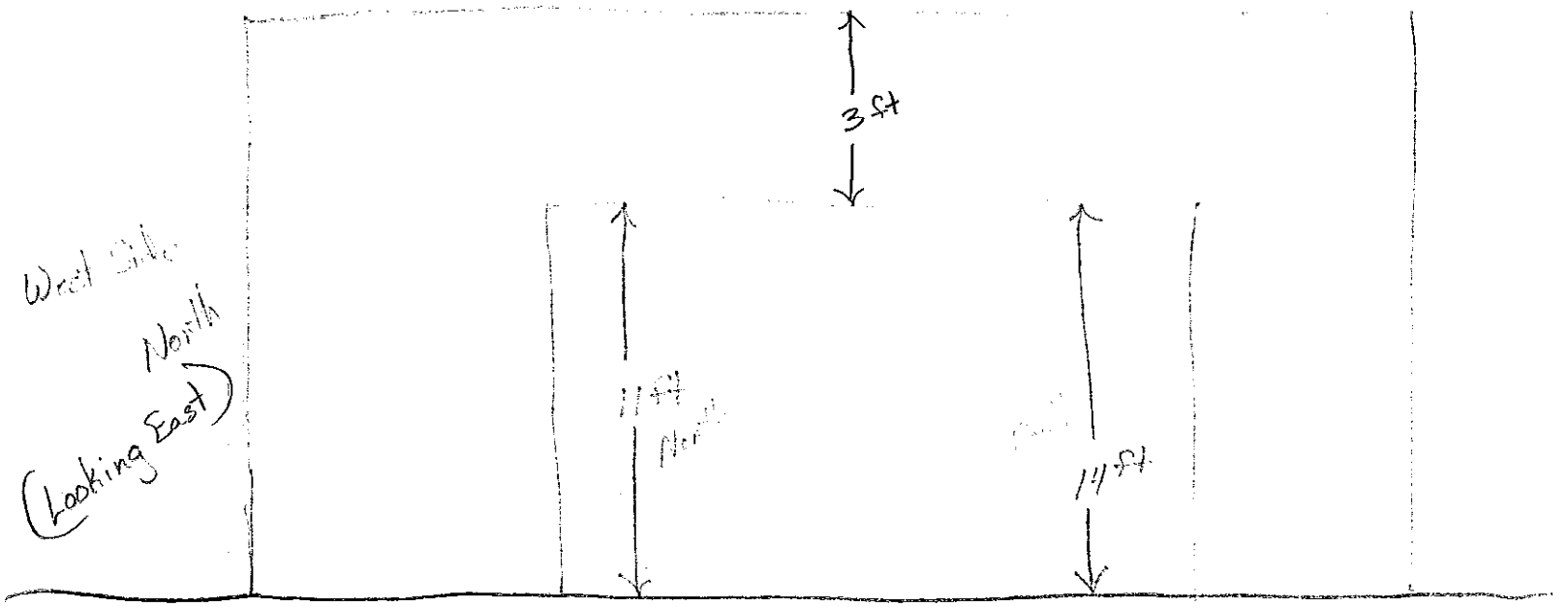


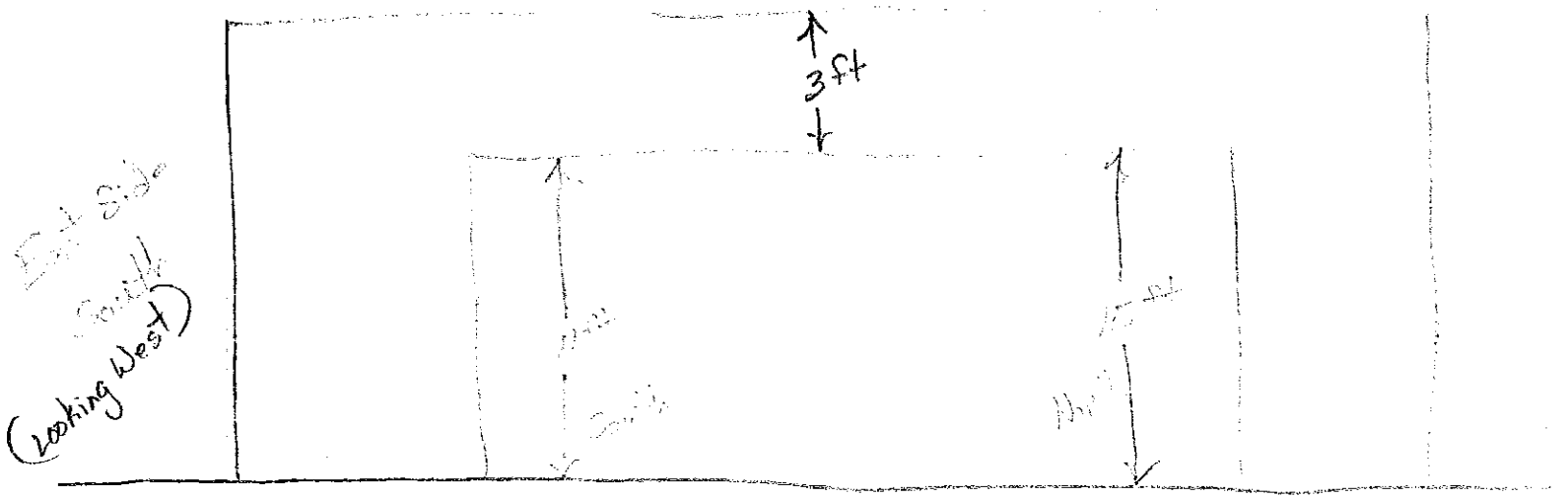
T5009090

PIER 6,
B12 9090
7-18-2012
(Top Looking Down)

FIELD MEASUREMENTS
TOM E. PUPPE







7/17/2012 AFTER RESET of BRG

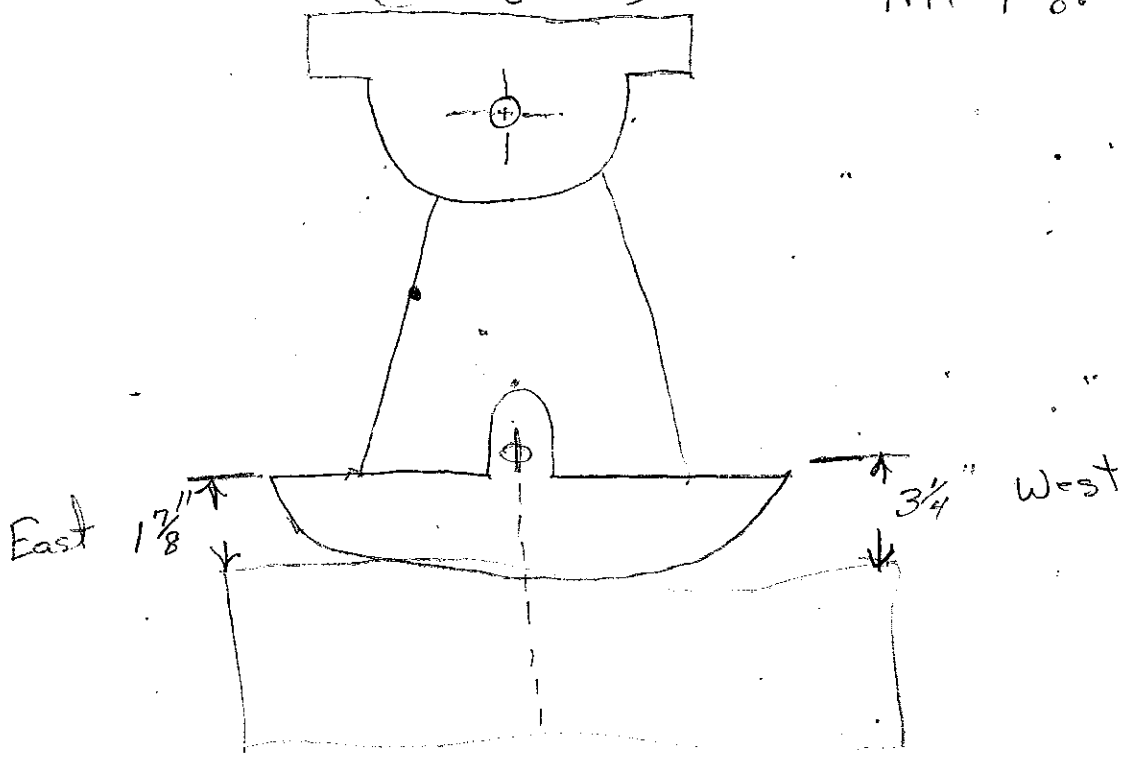
PIER 6, BR 9090

FIELD MEASUREMENTS
Tom PUPPE

as of 7-17-2012 TSO09090

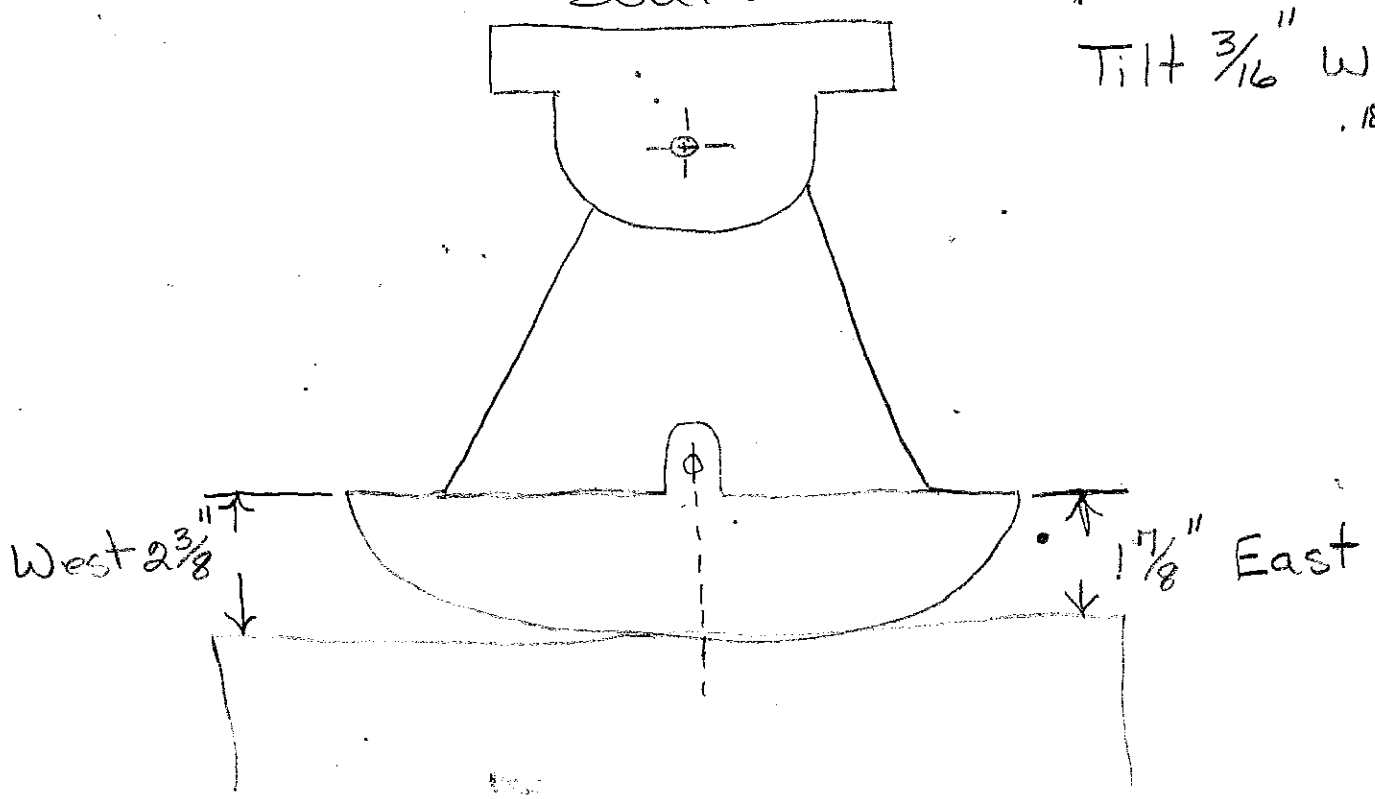
North Rocker
(Looking South)

Tilt 1 3/8" East

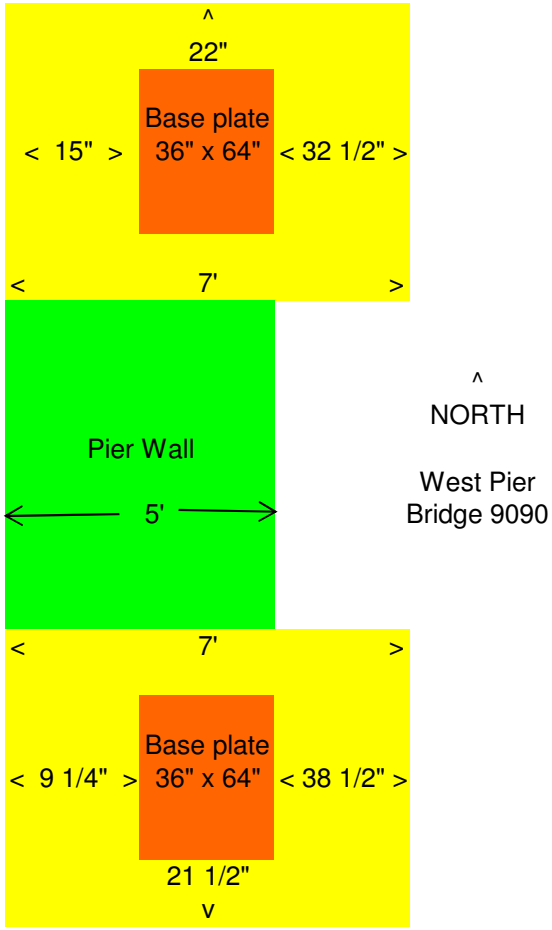


South Rocker (Looking North)

Tilt 3/16" West

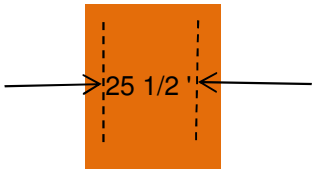


Pier cap measurements7/15/2012



83

Rocker bearing area is 25 1/2" wede



Rocker Bearing, South End of Pier 6

South End of Pier 6

L0 Connection at South End of Pier 6

Appendix C – Ground Movement

Appendix C contains a report prepared by the North Dakota Department of Transportation. This 8-page report describes installation and monitoring of slope inclinometers near Pier 6. The report was provided by MnDOT.

Kennedy Bridge

NDDOT Bridge No. 0002-358.090

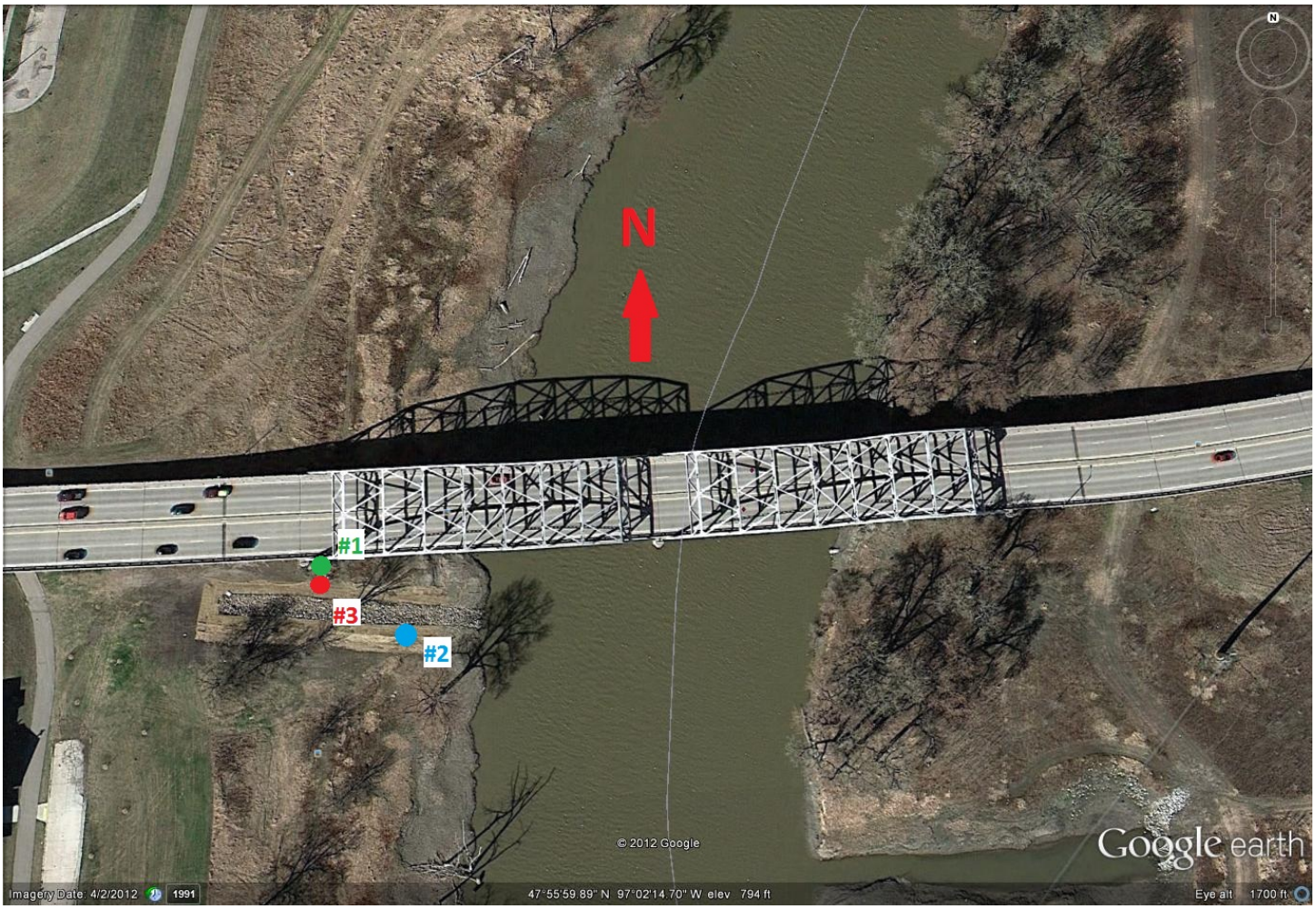
Hwy 2 RP 358.09

There is movement at the Kennedy Bridge West end-slope, and it is causing bent 5 and pier 6 to tilt.

Photo of Bent 5

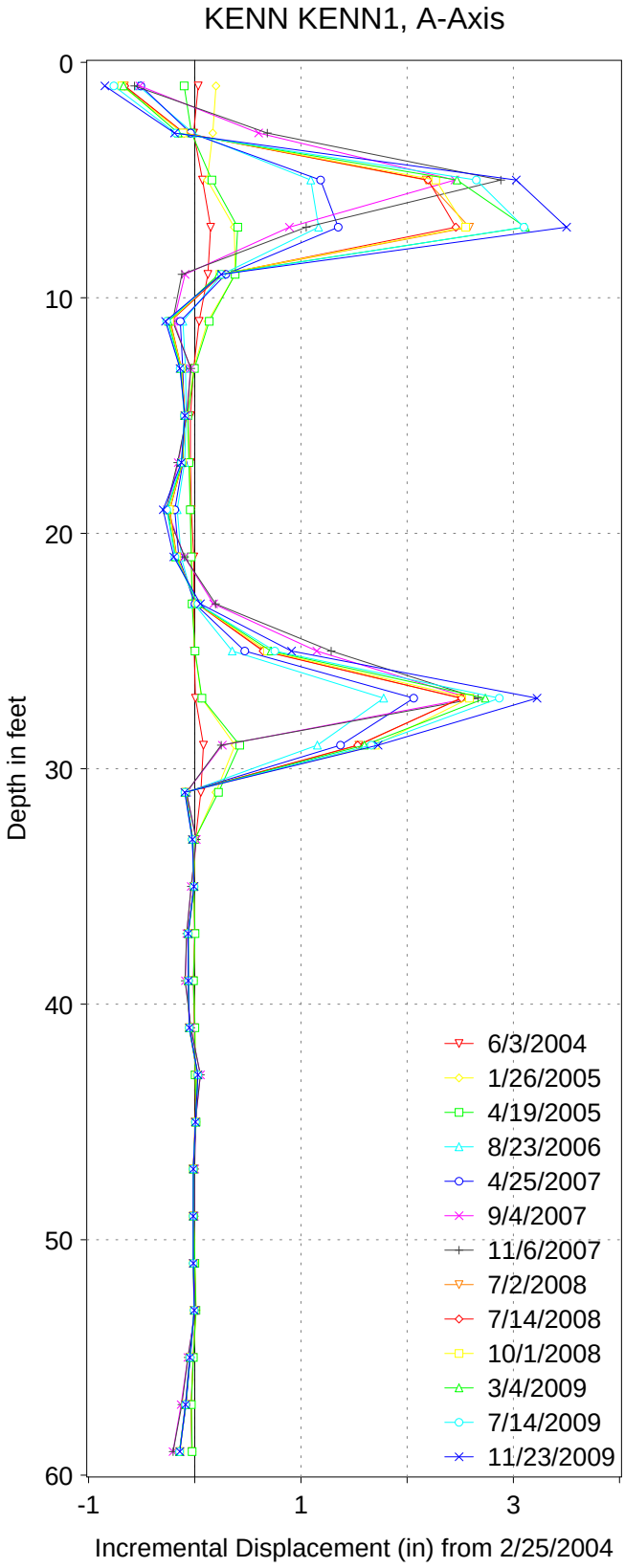
Investigation: The Corps installed three inclinometers in the Riverside Drive neighborhood which is just north of the Kennedy Bridge on the west bank. In the Corps investigation they discovered that, "this area has experienced foundation movements as evidenced by the existing failure scarp, pre-existing slickensides discovered during drilling, and the out of sequence geologic stratigraphy. Then larger noncircular failure surfaces that extended back to the secondary riverbank were analyzed."

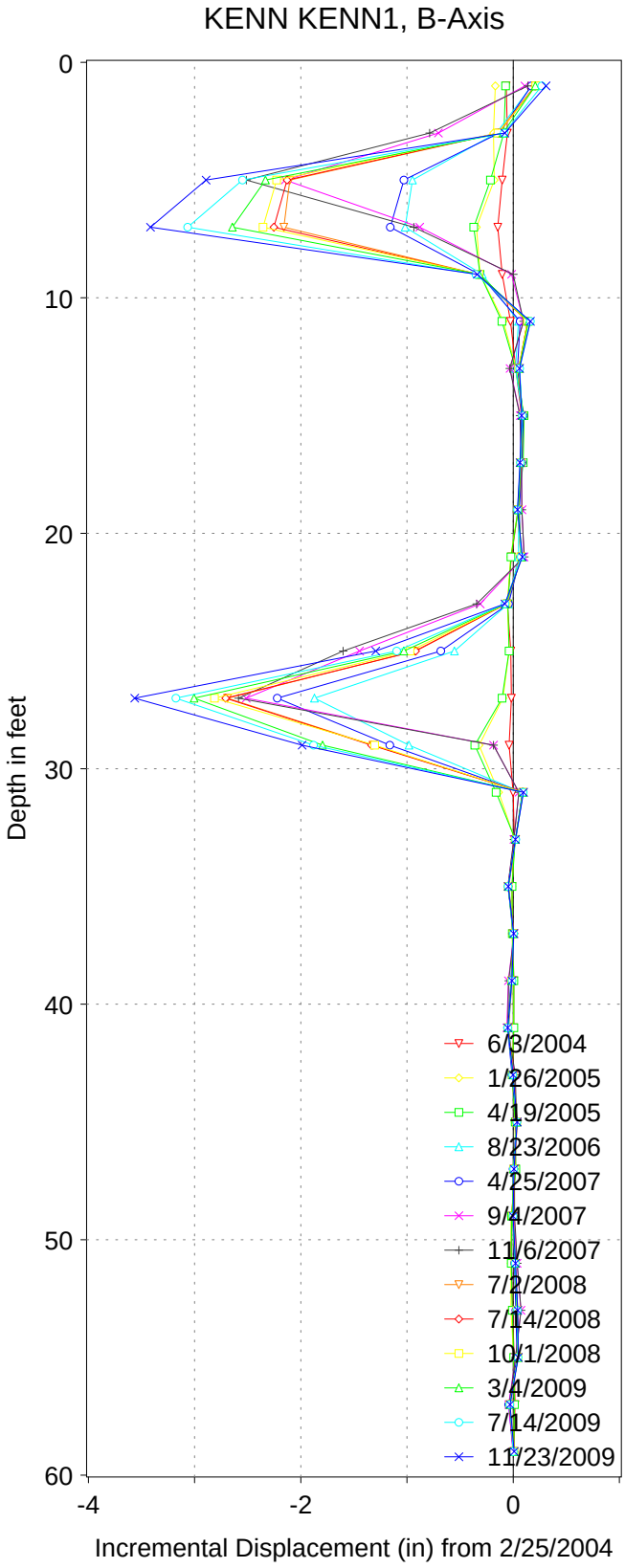
The NDDOT Geotechnical Section has monitored the west end-slope with inclinometers since 6/3/2004. We have installed three inclinometer tubes at this site. The tubes were placed on the south west side of the structure. The locations are shown in the following aerial image.



Aerial Image of Kennedy Bridge Showing the Inclinometer Locations

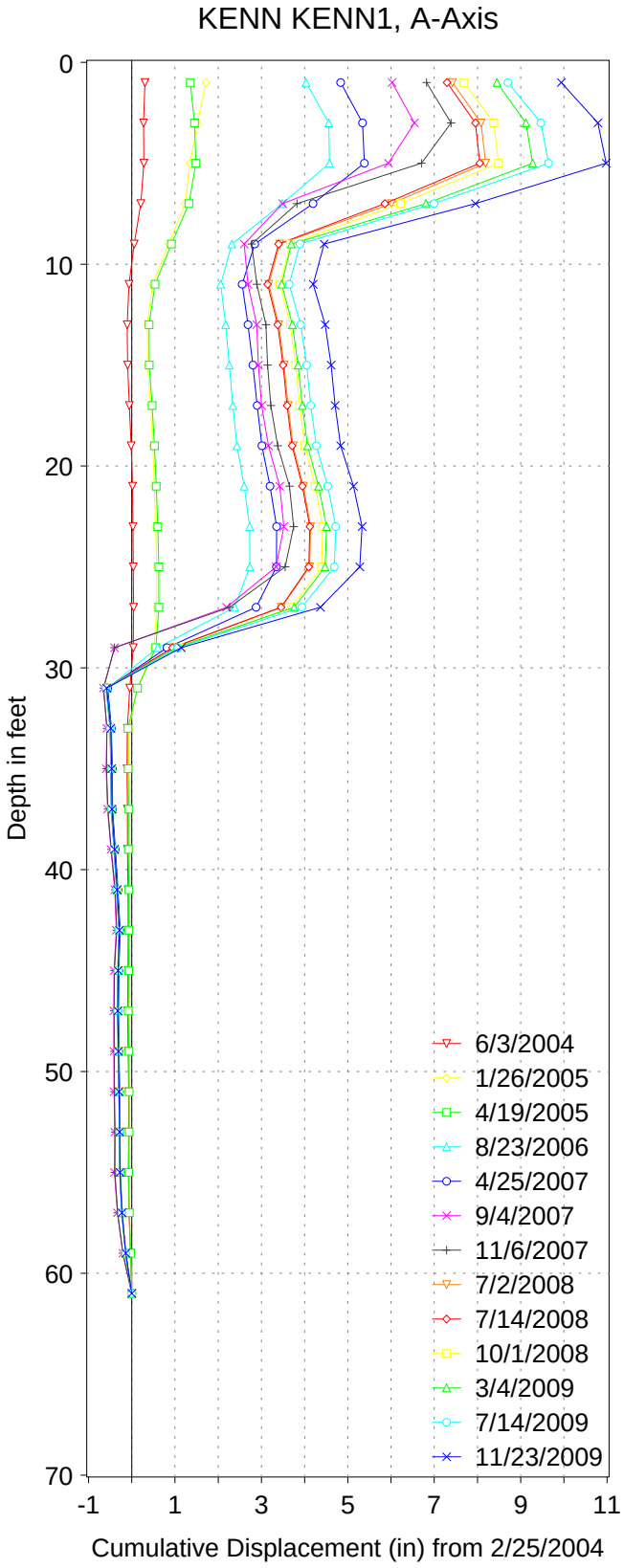
Tube #1 was sheared of in 2010 and tube #3 was installed to replace it. Tube #2 was installed, but it did not generate any valid readings as it was distressed by buoyant forces. The data from tubes #1 and tube #3 are on the following pages.

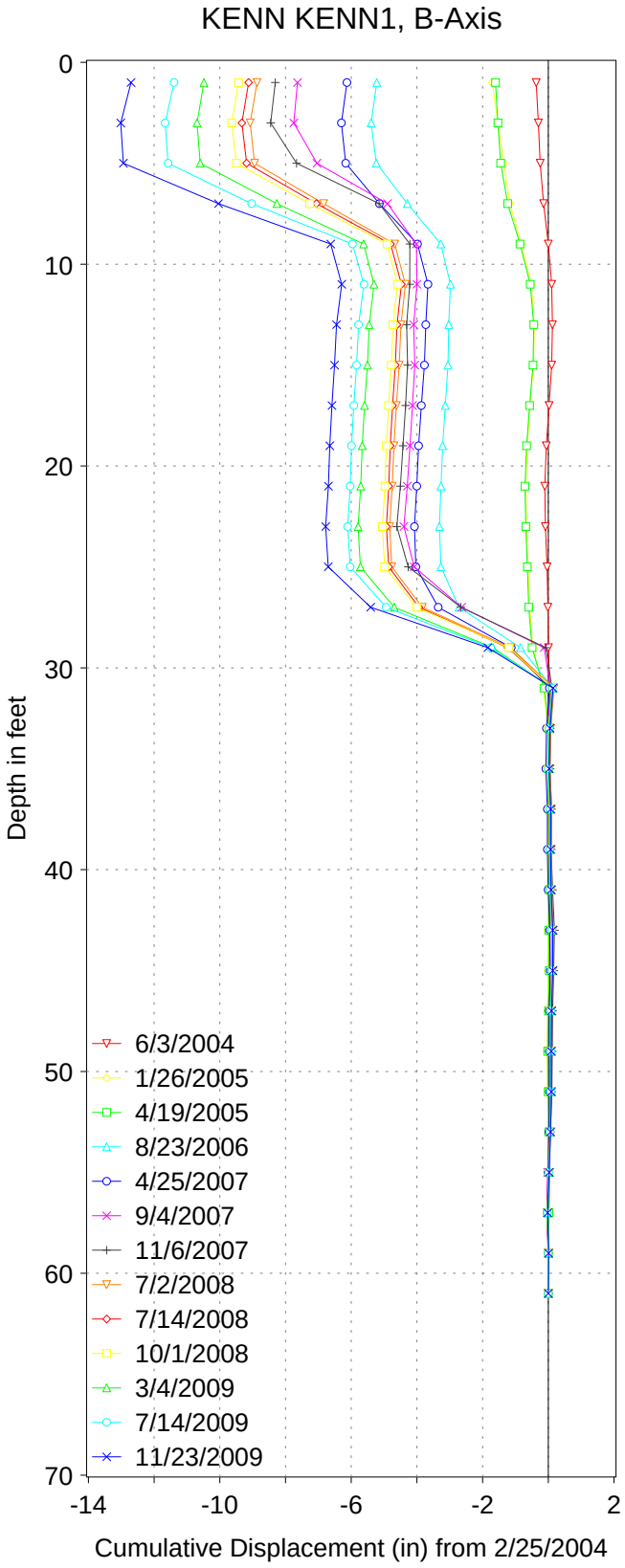




Incremental Displacement

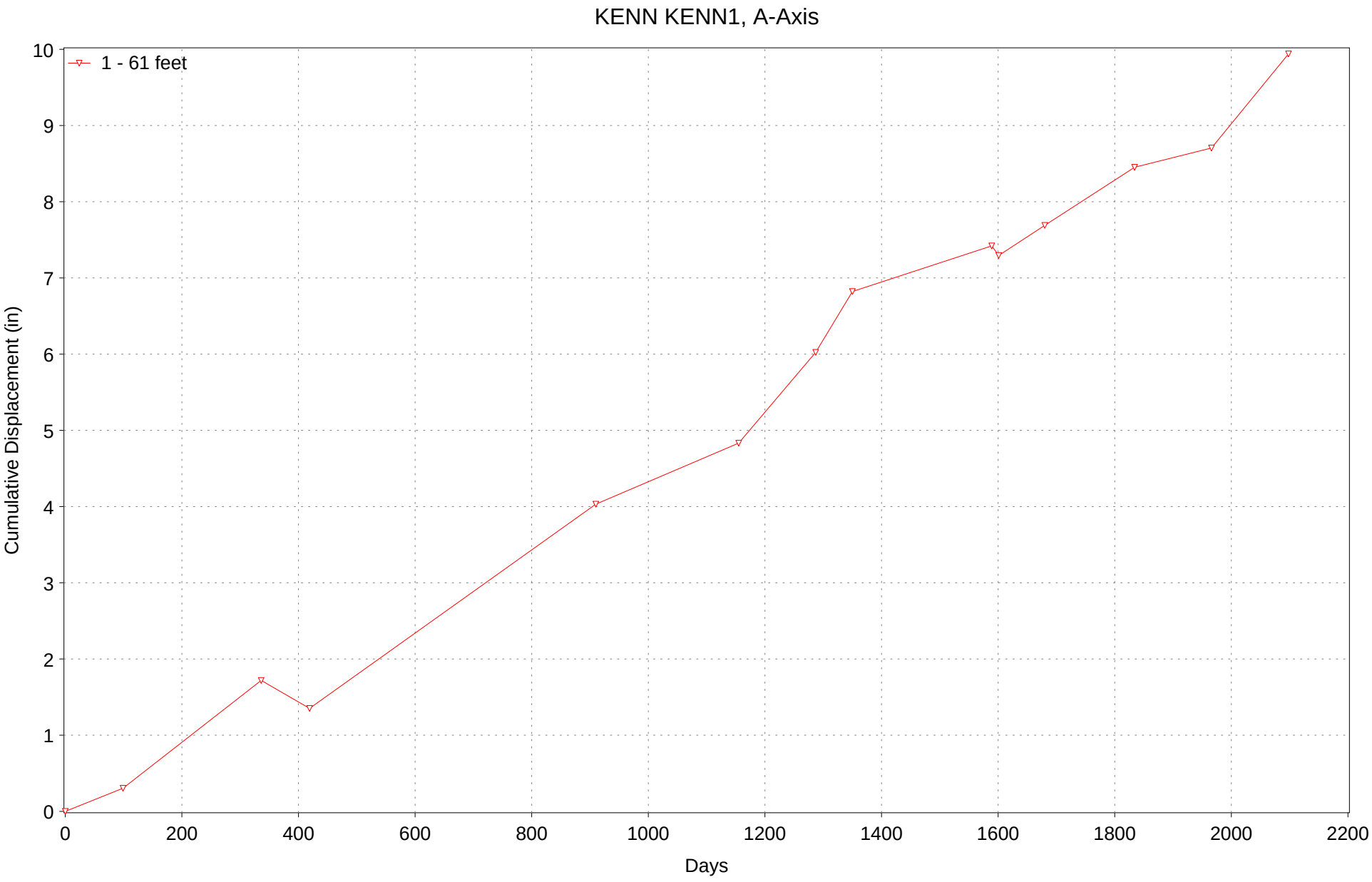
Tube #1





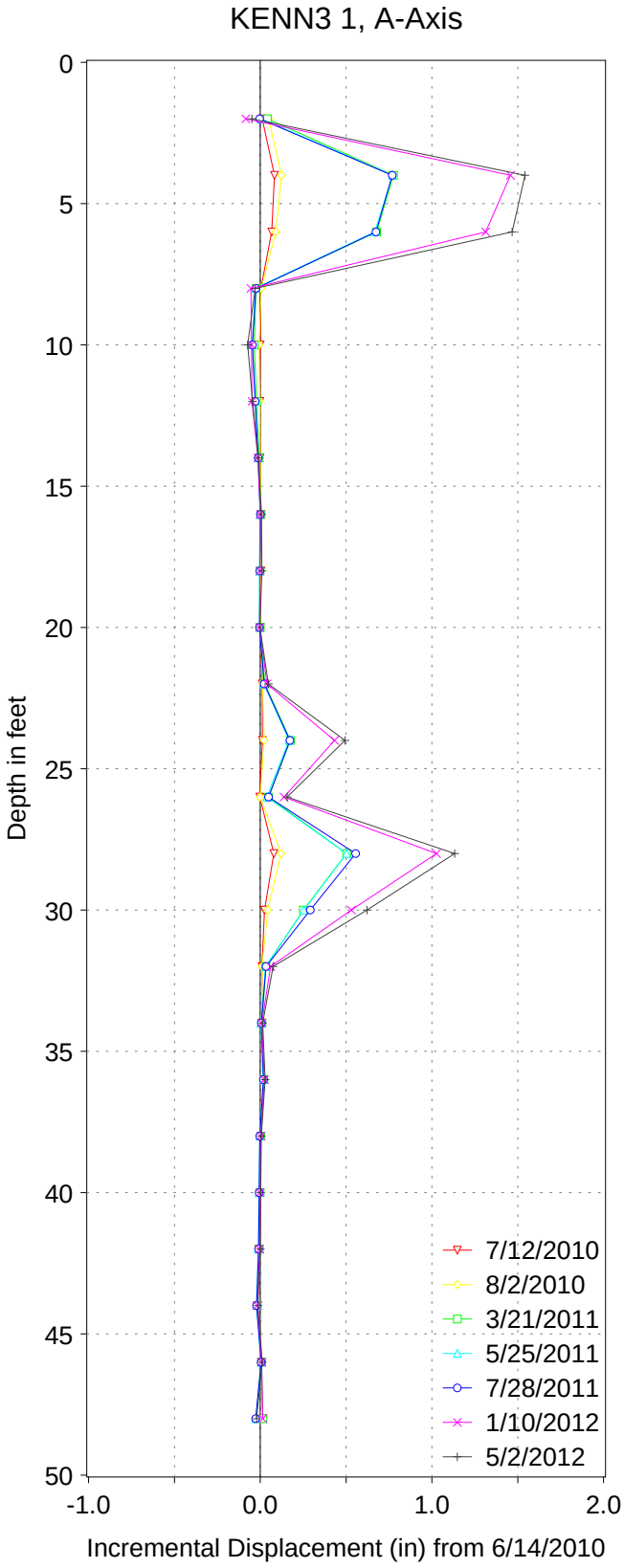
Cumulative Displacement

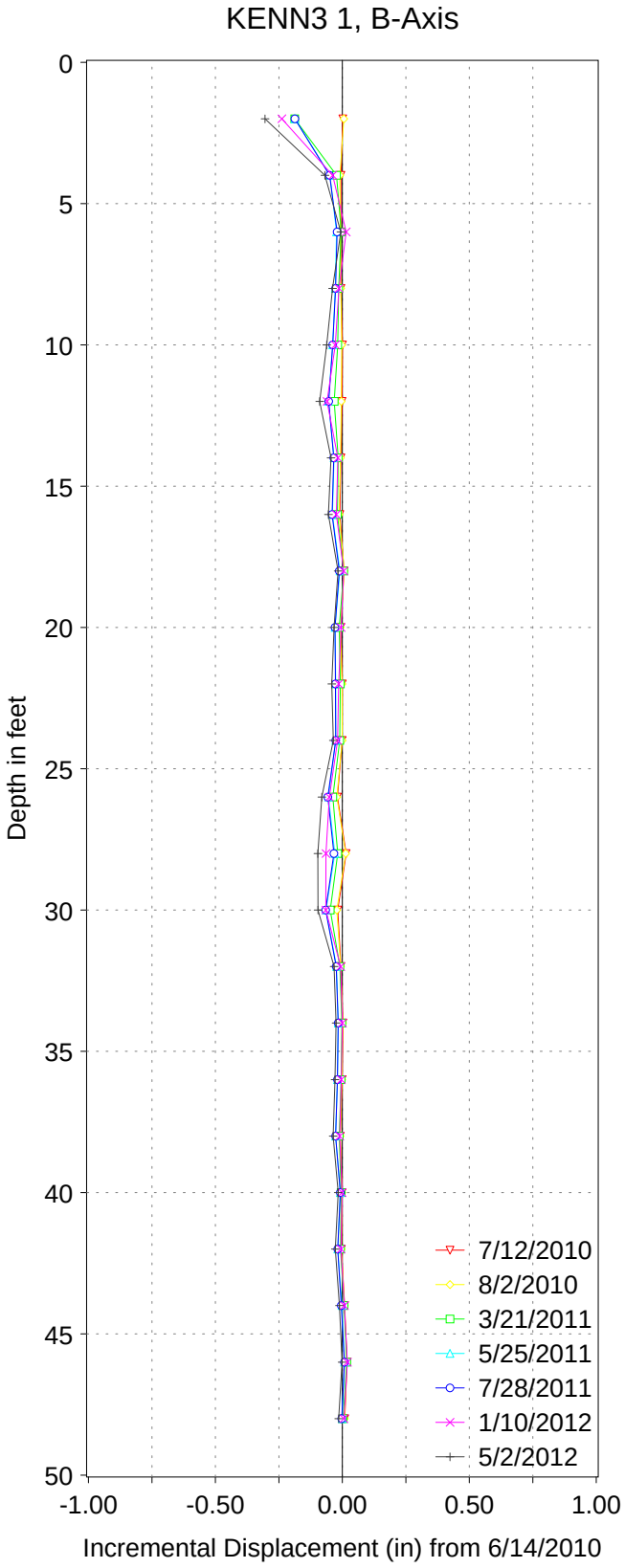
Tube #1



Time Displacement

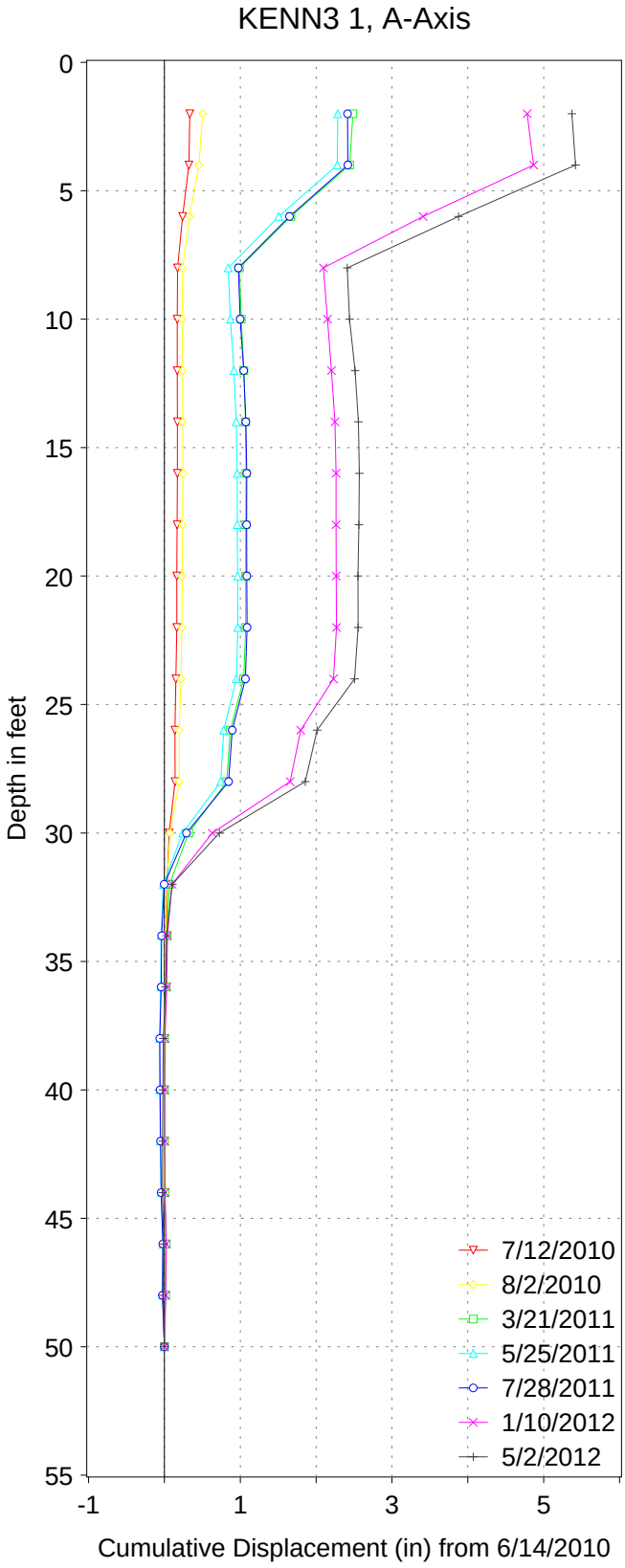
Tube #1

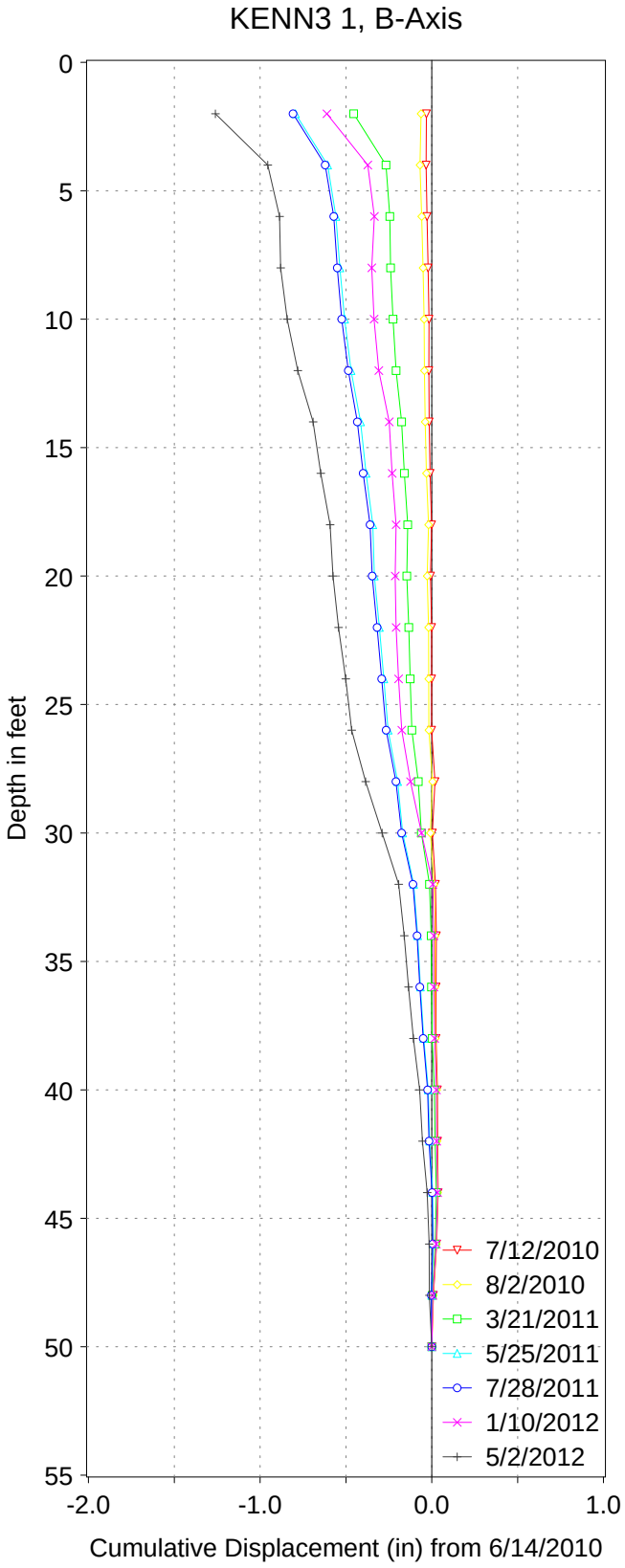




Incremental Displacement

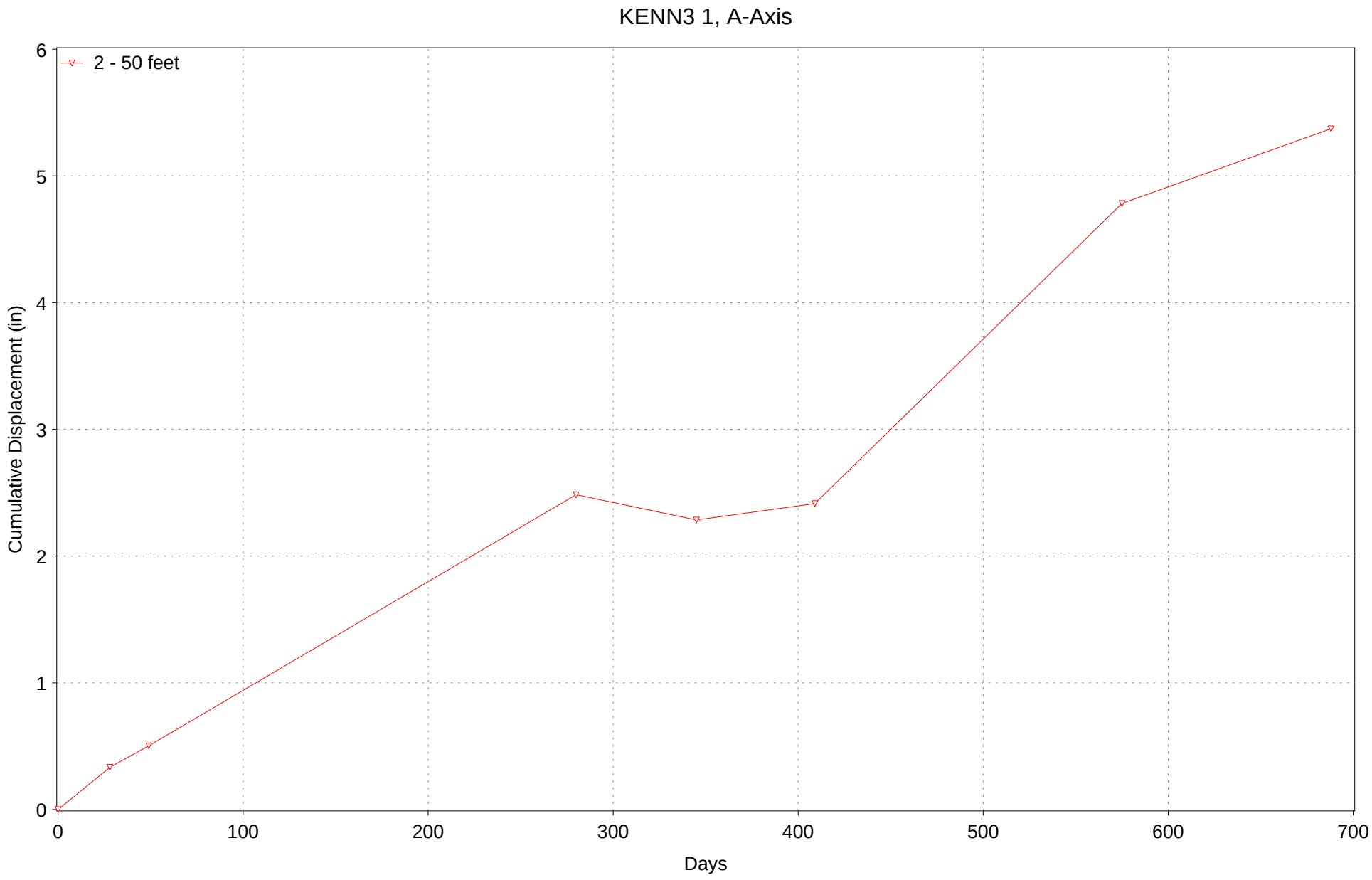
Tube #3





Cumulative Displacement

Tube #3



Time Displacement

Tube #3