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I am submitting herewith a thesis written by Mieah Dee Turner entitled "Structural Behavior of a Pile Framed Tie Back Retaining Wall." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Civil Engineering.

Richard Bennett, Major Professor

We have read this thesis
And recommend its acceptance:

Eric Drumm

Zhongguo Ma

Accepted for the Council:

Carolyn R. Hodges
Vice Provost and Dean of the Graduate School

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STRUCTURAL BEHAVIOR OF A PILE FRAMED TIE BACK RETAINING WALL

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Mieah Dee Turner
December 2009

Abstract

The objective of this research study is to analyze the preliminary structural behavior of a pile framed tie back retaining wall concept created by the Tennessee Department of Transportation (TDOT). Instrumentation is used to measure the forces and moments on the steel piles, loads on the anchors, and the pressure and displacement of the retained soil over time. Data collection for steel pile analysis consisted of the comparison of strain gage readings. Stress values were calculated from the readings and reduced down to an axial and bending force along the pile. Soil pressures that built up behind the wall were also evaluated over time by comparing gage readings and then calculating a pressure value. Preliminary results confirmed assumptions of rigid conditions of the retaining wall and negligible movement of the retained soil.

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Chapter 1: Introduction

1.1 Pile Framed Tie Back Retaining Wall Concept

In 2005, The Tennessee Department of Transportation launched the Smart Fix I-40 Project in Knoxville, TN, one of the largest road projects that the city has encountered. The project consisted of widening interstate 40, fixing problematic entrance/exit ramps, street construction, bridges, retaining walls, and a tunnel. The estimated project costs were close to $200 million. Out of the 31 required retaining structures, one access ramp adjacent to an historical residential area faced major land limitations and required a more complex design. (TDOT 2008)

A similar land limitation site challenged TDOT during the widening project of I-40/75 a few years earlier. The site was located at the West Hills eastbound exit ramp. Due to the pre-developed land surrounding the interstate, the major cost of land limitations was a concern to TDOT. In order for a typical cantilever retaining wall to be constructed the right-of-way behind the wall requires a minimum distance of the height of the wall. The required right-of-way was not possible without spending millions of dollars to acquire the land where an office building and commercial shopping center stood. Figure 1-1 shows the completed retaining wall and the limited right-of-way. The engineers at TDOT created a new retaining wall concept that used a top-down construction technique and H-pile framing called a pile framed tie back retaining wall. The wall is heavily reinforced to compensate for unknown forces that the wall experiences.

This research focuses on the second piling framed retaining wall of the Smart Fix I-40 Project with a goal to study the behavior of the retaining wall over time. The

Figure 1-1. Pile Framed Tie Back Retaining Wall at West Hills (Pate and Haddad 2007)

ultimate objective of the research study is to evaluate the behavior of the wall and reduce structural elements used in construction in order to reduce material costs.

1.2 Smart Fix Wall # 7

The second pile framed tie back retaining wall constructed by TDOT is adjacent to the Hall of Fame Drive entrance ramp on westbound I-40 near downtown Knoxville, TN, Figure 1-2. Directly in front of the historic 4th and Gill residential neighborhood, Wall # 7 of the Smart Fix Project encounters the same land acquisition limitations as the first retaining wall at the West Hills site and for this reason s pile framed tie back retaining wall was selected. The retaining wall is approximately 600 feet long with a height of 35 feet at the highest point on the wall. Two sections of the wall were selected to analyze loads, wall movement, and soil pressures that the wall will undergo with time. Section 1 is located at station 11+75 and Section 2 is located at station 12+50. Figure 1-3

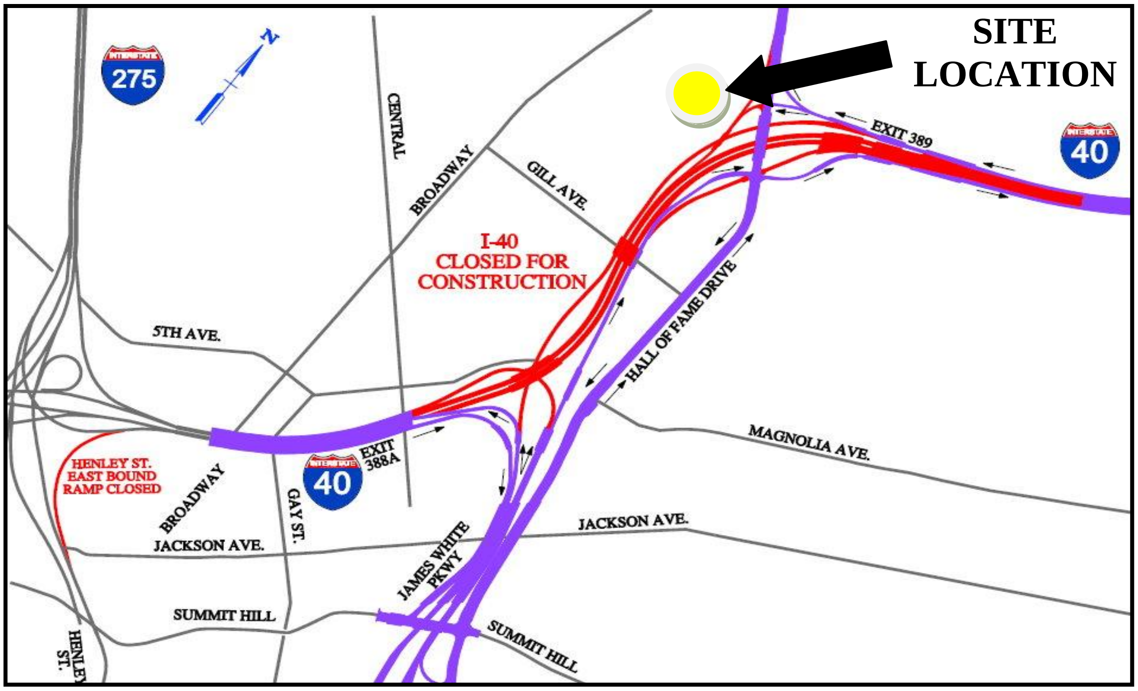


Figure 1-2. Location of Researched Retaining Wall (TDOT 2008)

shows the contract wall elevation drawing along with a detailed photo of the two test sections. Instrumentation used is described in Chapter 2.

1.2.1 Soil Conditions

The geotechnical investigation was performed by Wilbur Smith Associates, Inc. Overall the soil conditions consisted mostly of 5 feet of clay fill followed by interbedded calcareous sandstone and calcareous shale. The report also indicates a variety of areas with weathered rock and rock. (Wilbur Smith Associates, Inc. 2006) Figure 1-4 shows the excavated retaining wall and the two instrumented sections.

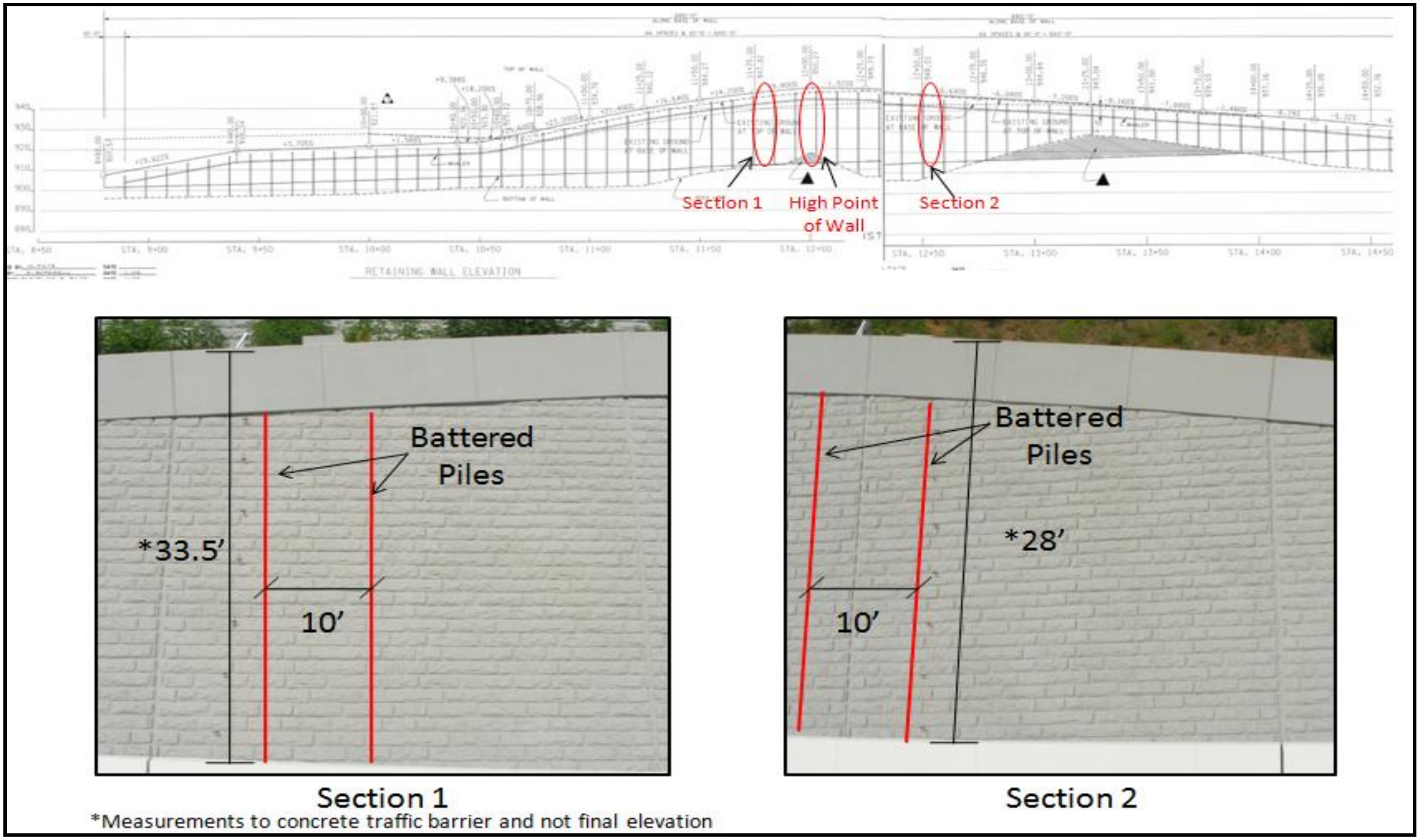


Figure 1-3. Wall Elevation

Figure 1-4. Soil Profile of Excavated Wall

1.2.2 Structure Design

The framed of the pile framed tie back retaining wall is HP 10x42 battered piles and HP 12x52 vertical H-piles that are connected by a HP 10x42 whaler, all piles are Grade 50 steel. Each wall section is made up of a battered and vertical pile pair that are driven into the soil in to competent rock and connected by a 10 foot whaler. Angle accuracy of the battered piles is very important in the construction of the retaining wall. In order to maintain accuracy, temporary vertical piles are first driven into the soil to help guide the battered piles. The battered piles are driven in at an angle 18° away from the vertical piles and spaced 10 feet apart. The whaler is welded to the battered pile. If the battered pile reaches rock at an elevation higher than the final grade, the pile is anchored into the rock, Figure 1-5. In the west battered pile of test section 1 met this case. However, the battered pile was later extended approximately 10 feet because the rock was found to be weathered, Figure 1-6. Two 4 ½ inch diameter holes are drilled and cased through this whaler to competent rock. The 1½ inch diameter rods are inserted and grouted in the casing. The permanent vertical pile is installed and the temporary vertical pile removed. Figure 1-7 and 1-8 illustrate the design detail of each 10 feet section of wall.

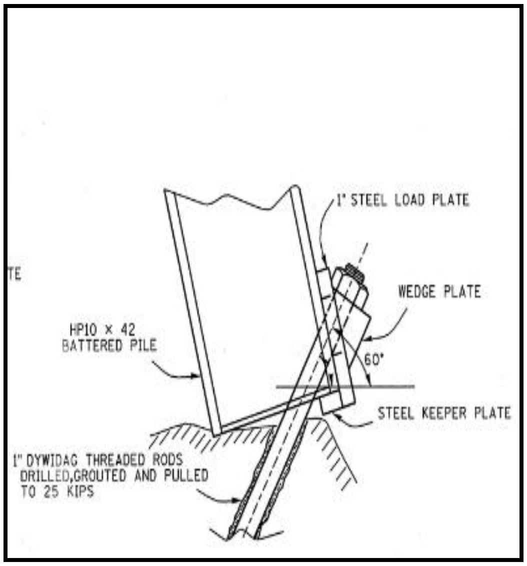


Figure 1-5. Pile Anchorage Detail (TDOT Design Drawing M483-392E)

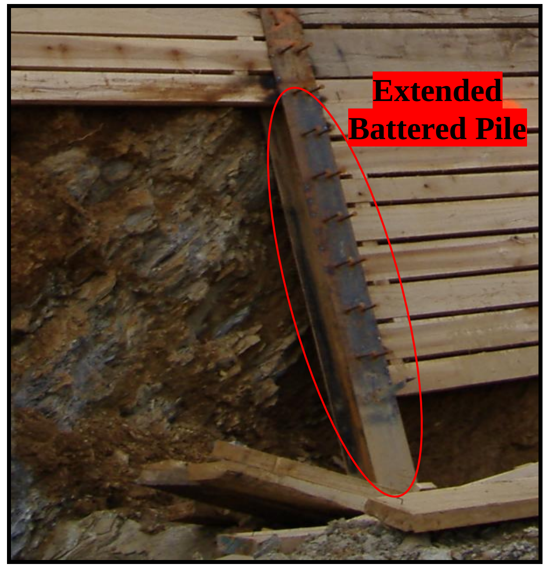


Figure 1-6. Section 1W extended pile

1.2.3 Construction Details

After the construction of the main structural wall components, excavation lifts of approximately 7 feet take place, Figure 1-9. After each excavation lift, wood lagging is installed between the battered piles in order to hold back the soil. Once final elevation is reached, shear studs are welded on the battered piles, the concrete form for the face of the wall is erected and the face is poured, followed by the forming and pouring of the concrete parapet. The compressive strength of the concrete is specified as 4 ksi in the drawing plans, but was changed to 3 ksi which results in a modulus of elasticity of about 3120 ksi. Figure 1-10 shows a detailed construction timeline showing all major construction events which include excavation lifts, concrete face pours, concrete parapet pours, and the point where the automated data acquisition system begins.

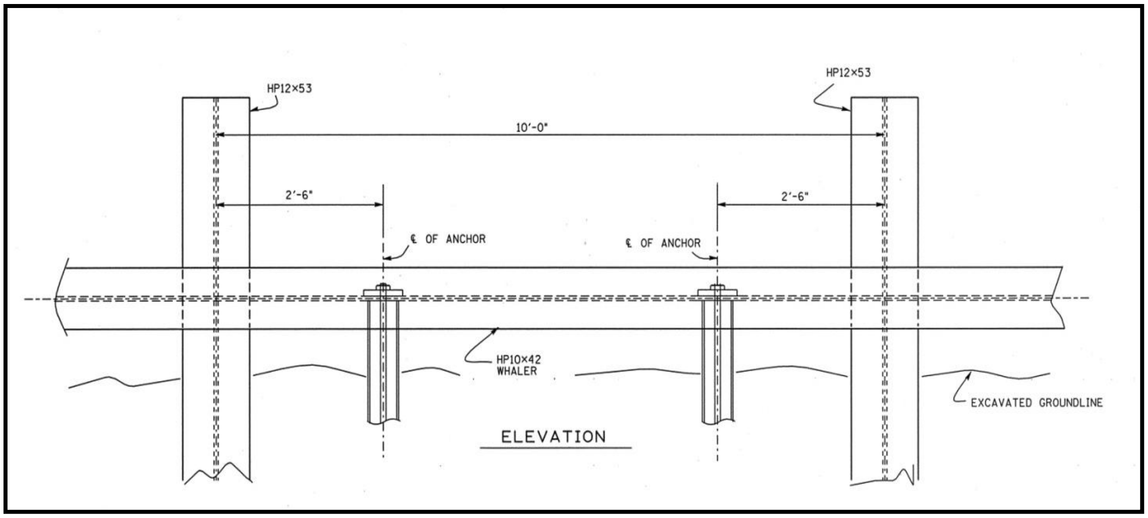


Figure 1-7. Typical Section Detail
(TDOT Design Drawing M483-392D)

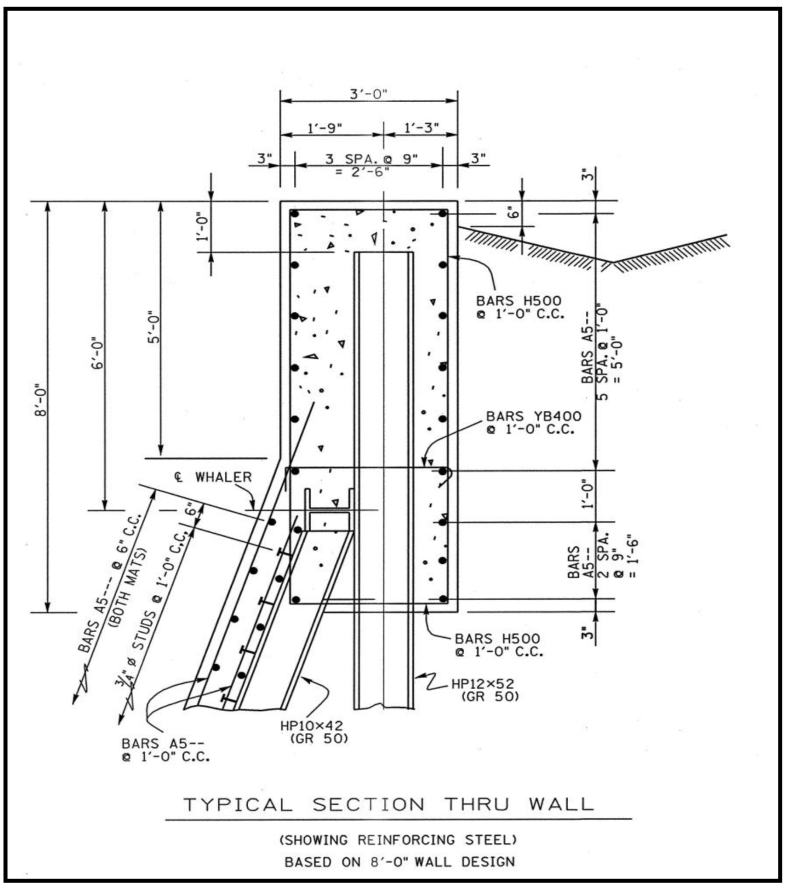


Figure 1-8. Typical Wall Detail
(TDOT Design Drawing M483-392F)

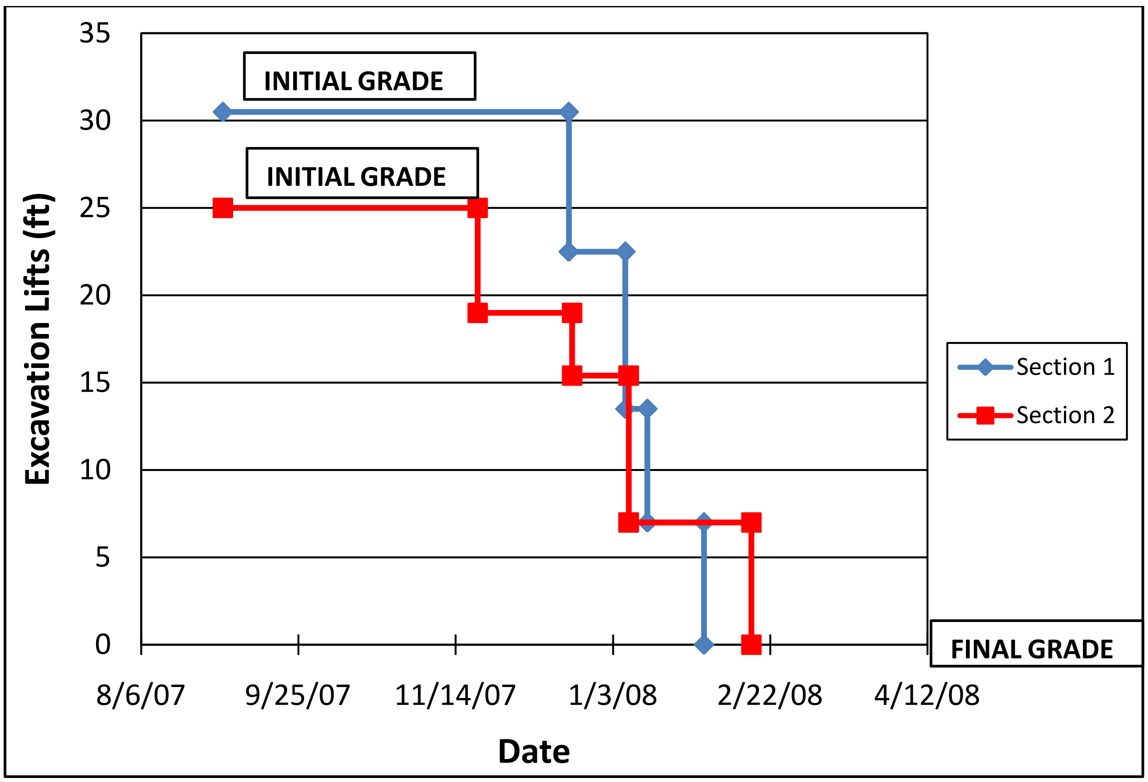


Figure 1-9. Excavation Lifts

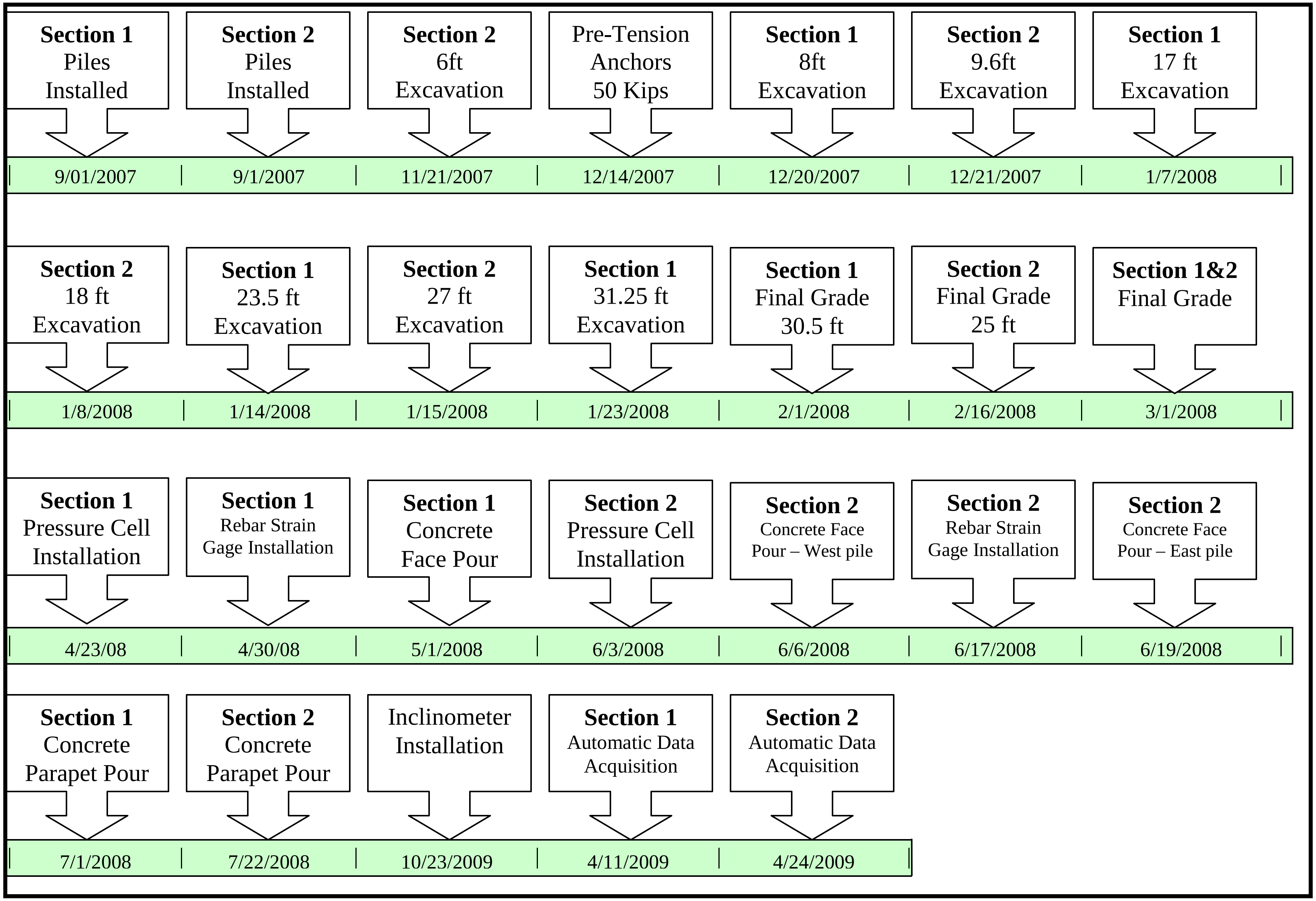


Figure 1-10. Construction Timeline

Chapter 2: Instrumentation

2.1 Vibrating Wire Technology

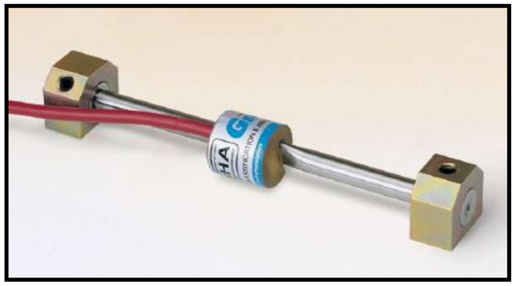
Vibrating wire Instrumentation was installed on the pile framed tie back retaining wall to collect data. The Geokon Model GK 403 Readout Box was used during the construction phase for collecting data for all instruments on the retaining wall, excluding the inclinometer device. After completion of the construction phase. A Campbell Scientific automated data acquisition system was installed. The data acquisition equipment measures frequencies by strumming the electric coil that is attached to each instrument. This coil initiates the vibrating wire and transfers the frequency of the vibrating wire to the data acquisition system which converts it to engineering units of strain. Figure 2-1 displays the GK 403 Readout Box along with all instrumentation that is installed on the pile framed tie back retaining wall.

2.2 Strain Gage

The strains at selected points along the steel piles are measured using the Model 4000 Arc Weldable Strain Gage from Geokon. The six inch strain gage is made up of a steel bar with two support blocks located on each end, with the support blocks welded to the steel piles. The frequency in the strain gage changes with the pile loading. An increase in strain reading indicates tension and a decrease indicates compression.

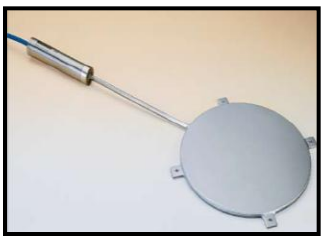
The strain gages are installed on the research test sections in pairs of two on the webs of the vertical, battered, and whaler piles. They are welded on both sides of the web to examine the moments in the strong and weak axis of the piles, x-axis and y-axis

a) GK 403



b) Strain Gage

c) Load Cell



d) Earth Pressure Cell

e) Rebar Strain Gage

f) Inclinometer

Figure 2-1. Instrumentation
(www. geokon.com)

respectively. In order to protect the strain gages from being damaged during the pile drives, a 1/4 inch steel plate was welded to the tip of the flanges creating a barrier between the soil and the strain gages. The gages are mounted 8 feet from the tip of the vertical pile and 5 feet from the tip of the battered pile. Each gage is spaced the same depending on the pile, either 8 or 5 feet. Figure 2-2 shows the layout of Section 1 W vertical and battered piles, the arrangement for the strain gage pairs, and the steel plate barrier. Figures 2-3 thru 2-5 show the remaining test section steel pile pairs, see B.1 of the Appendix for a more detailed layout.

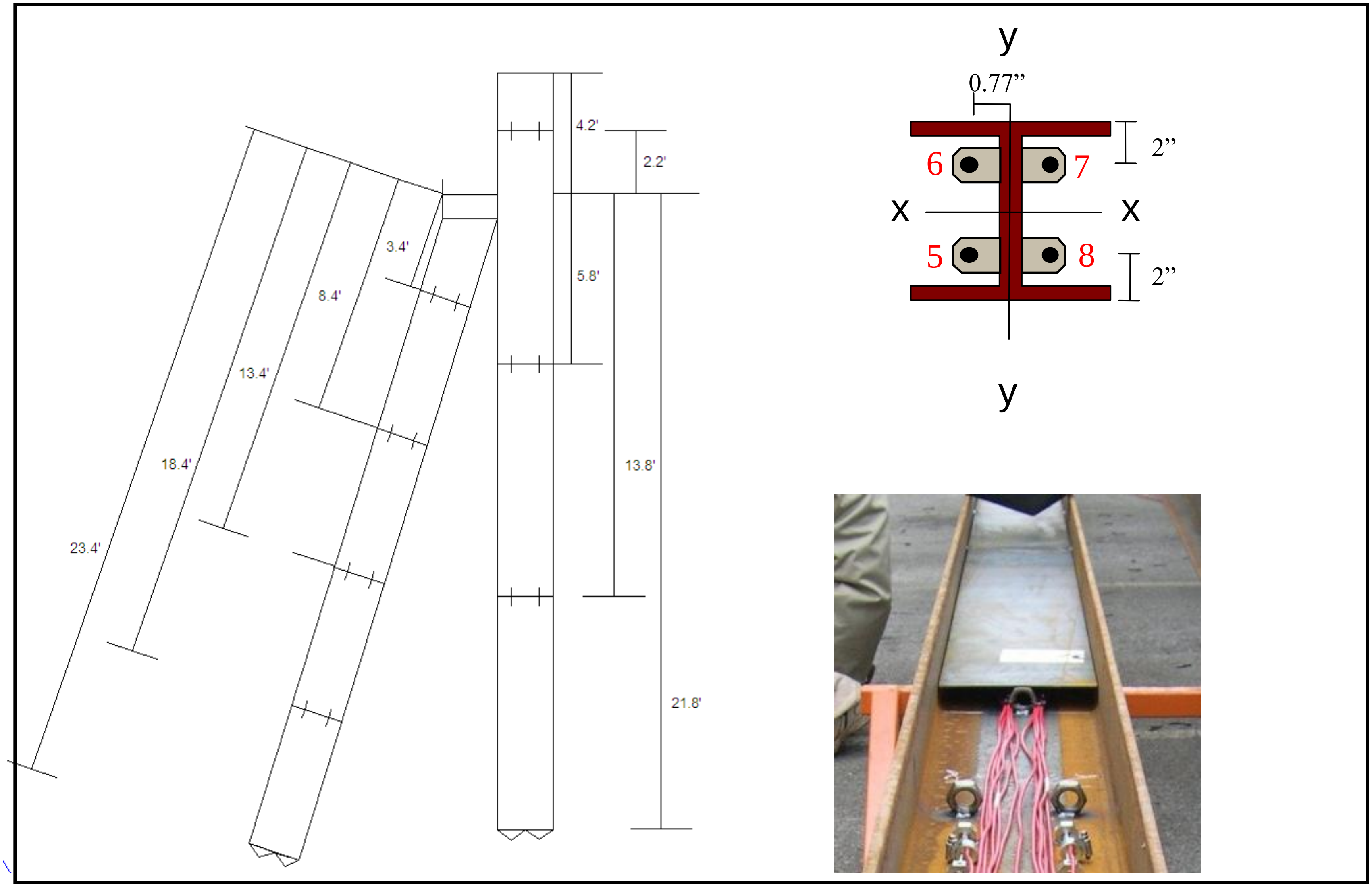


Figure 2-2. Strain Gage Layout of Section 1 W, with typical gage layout

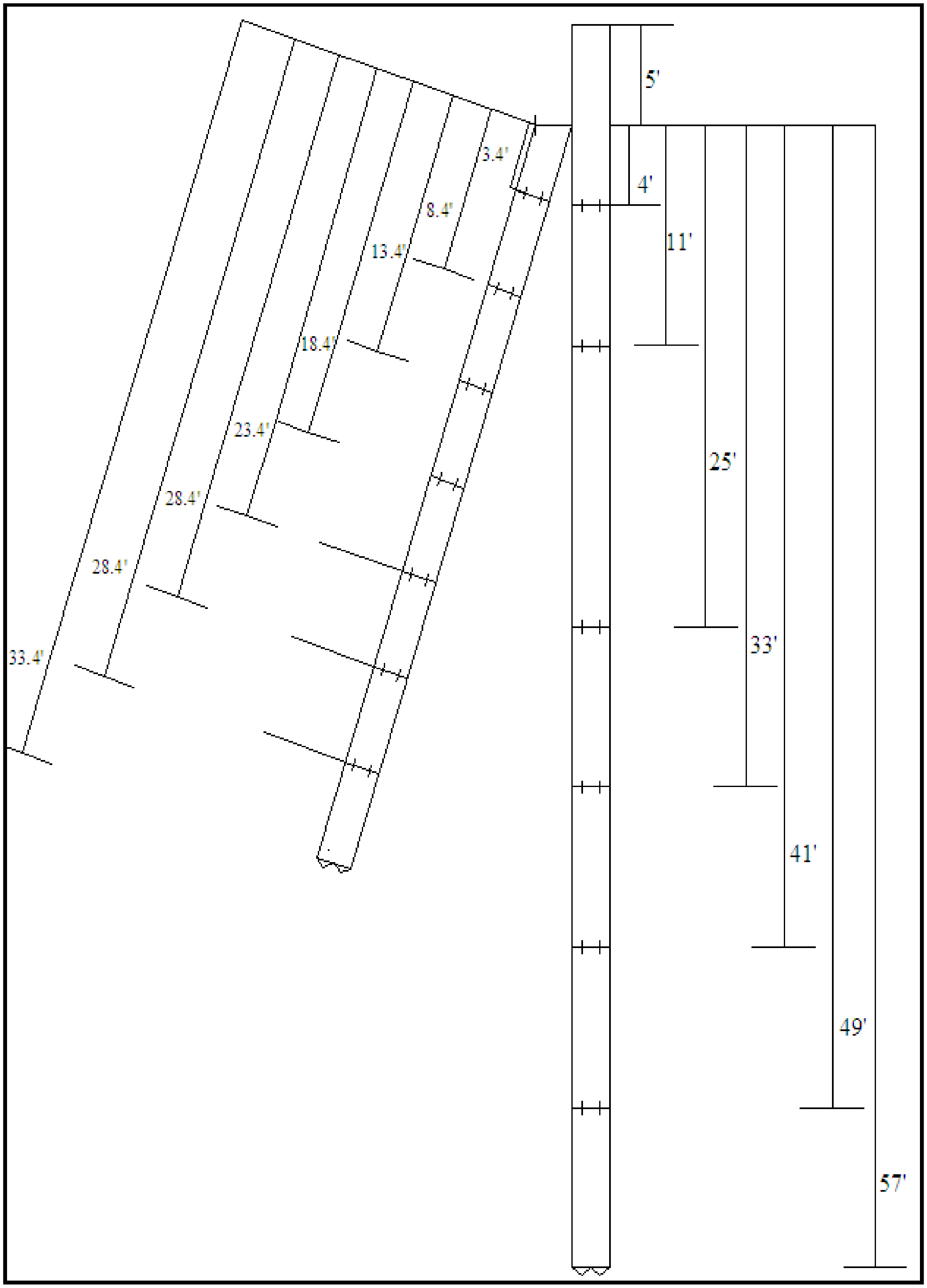


Figure 2-3. Strain Gage Layout of Section 1 E

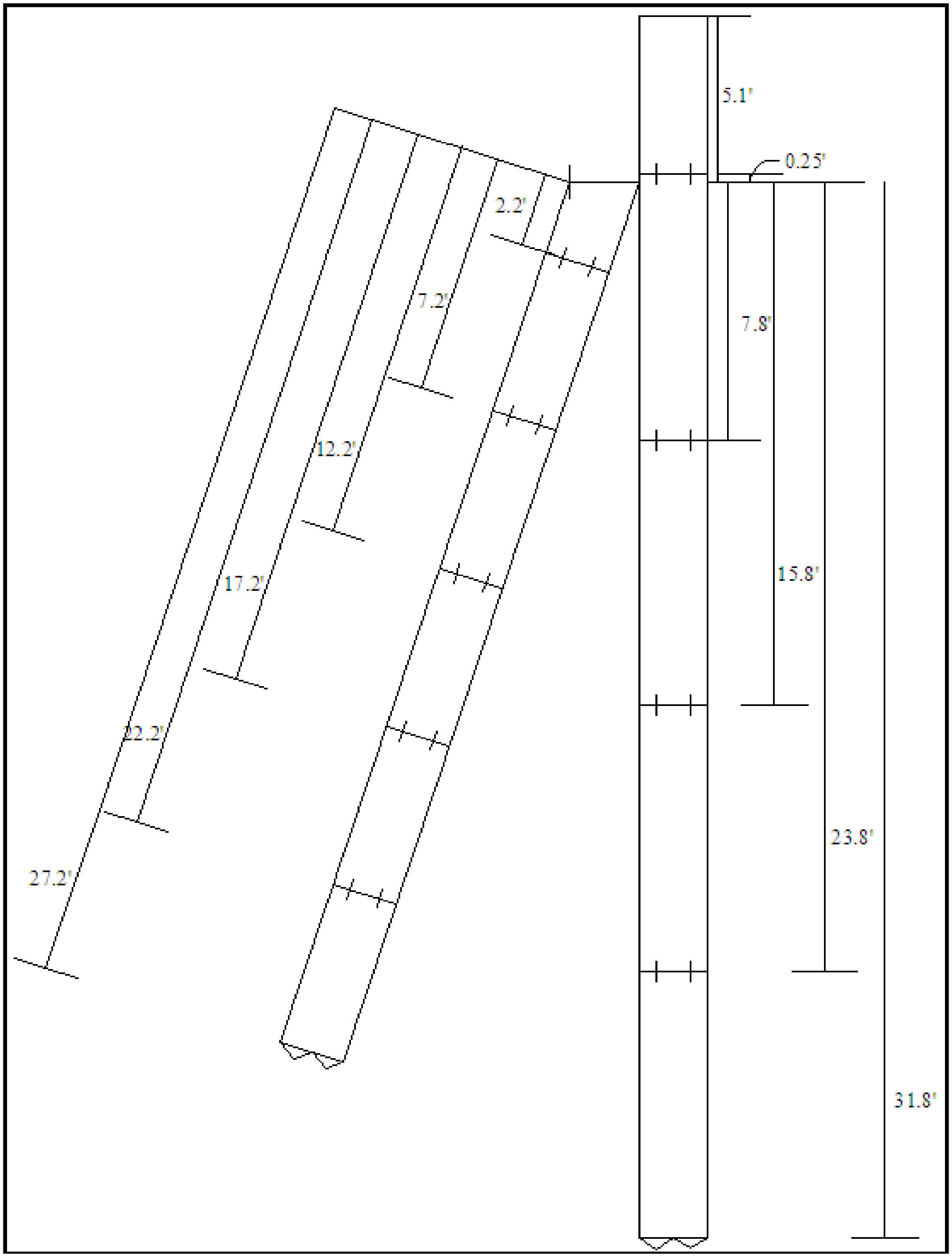


Figure 2-4. Strain Gage Layout of Section 2 W

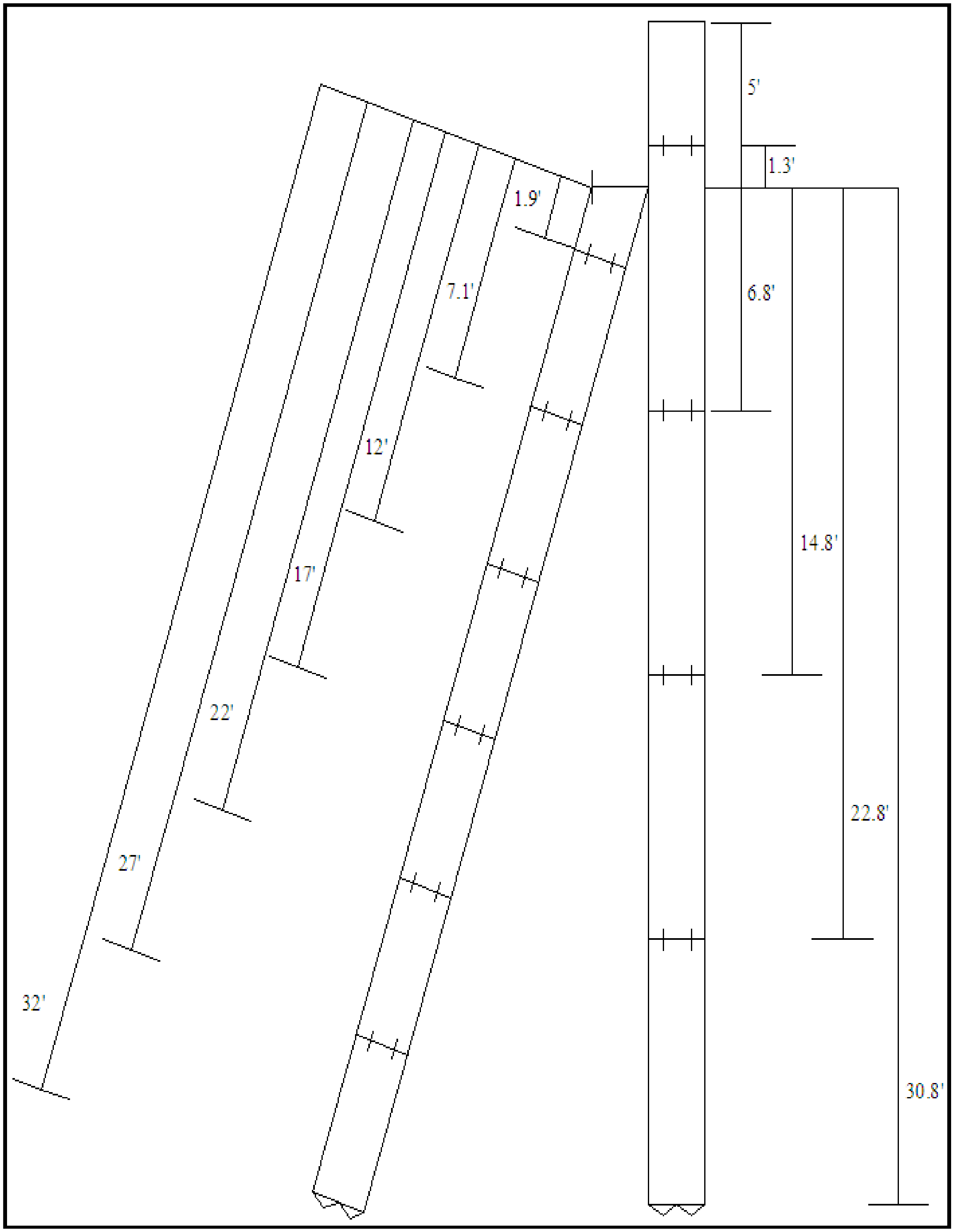


Figure 2-5. Strain Gage Layout of Section 2 E

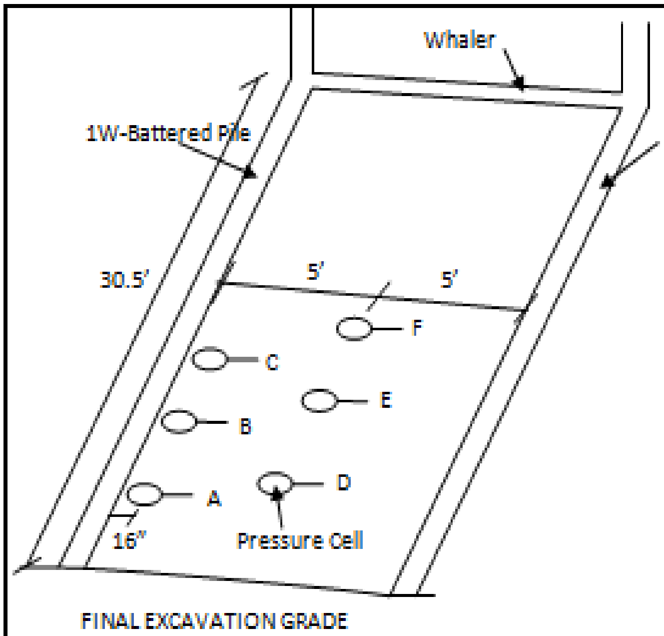
2.3 Load Cells

Geokon Model 4900 Load cells are installed on each of the two anchors located between the vertical piles. The load cells are cylindrical steel devices that are placed around each anchor. The load cell consists of three sensors that each contain six vibrating wires. The sensors are averaged together to find a more accurate reading and overcome any eccentricity that the bearing plate causes. As the anchor takes on loads an increase in reading occurs when the anchor rod is in tension.

2.4 Pressure Cells

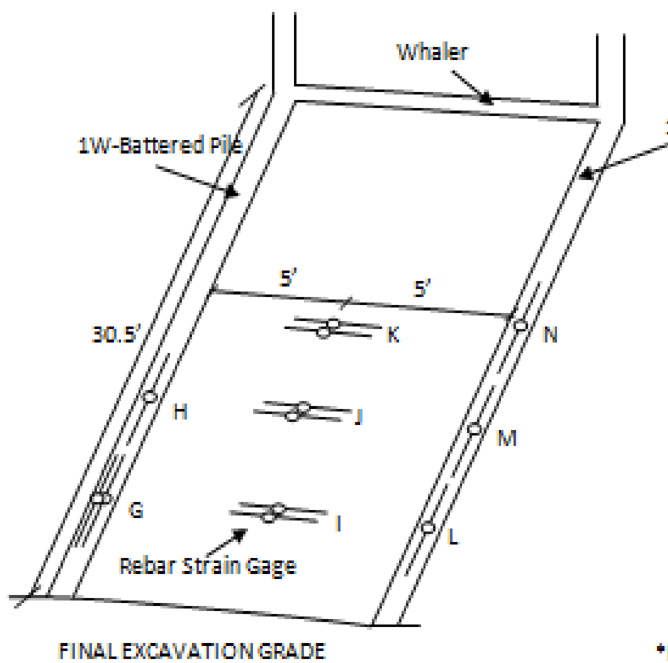
Soil pressures that build up on the wall are measured by the Geokon Model 4800 Earth Pressure Cells. The earth pressure cells are constructed of two attached steel plates with hydraulic fluid between them. As the plates are compressed by the soil pressure, the hydraulic fluid is pressurized and converted to an electrical output using the vibrating wire technology. Compression of the earth pressure cell is indicated by an increase in reading from the initial value on the GK 403 Readout Box.

The location of the earth pressure cells are based on results from a finite element analyses (Branch 2007). In the study, ADINA software was used to determine earth pressures produced for various soil profiles and soil types in pile framed tie back retaining walls. The results of the analyses showed a large increase in earth pressures deeper in the soil close to final elevation (Branch 2007). Based on this pressure distribution, the earth pressure cells were installed to be placed at 1/6, 1/3, and 1/2 the height of the wall, Figures 2-6 and 2-7 show a sketch of the layout and Figures 2-8 and 2-



Label	Name	*Height
A	EP 1 e 4	4'-11"
B	EP 1 e 8	9'
C	EP 1 e 12	13'-3"
D	EP 1 c 5	5'-9"
E	EP 1 c 10	10'-8"
F	EP 1 c15	15'-8"

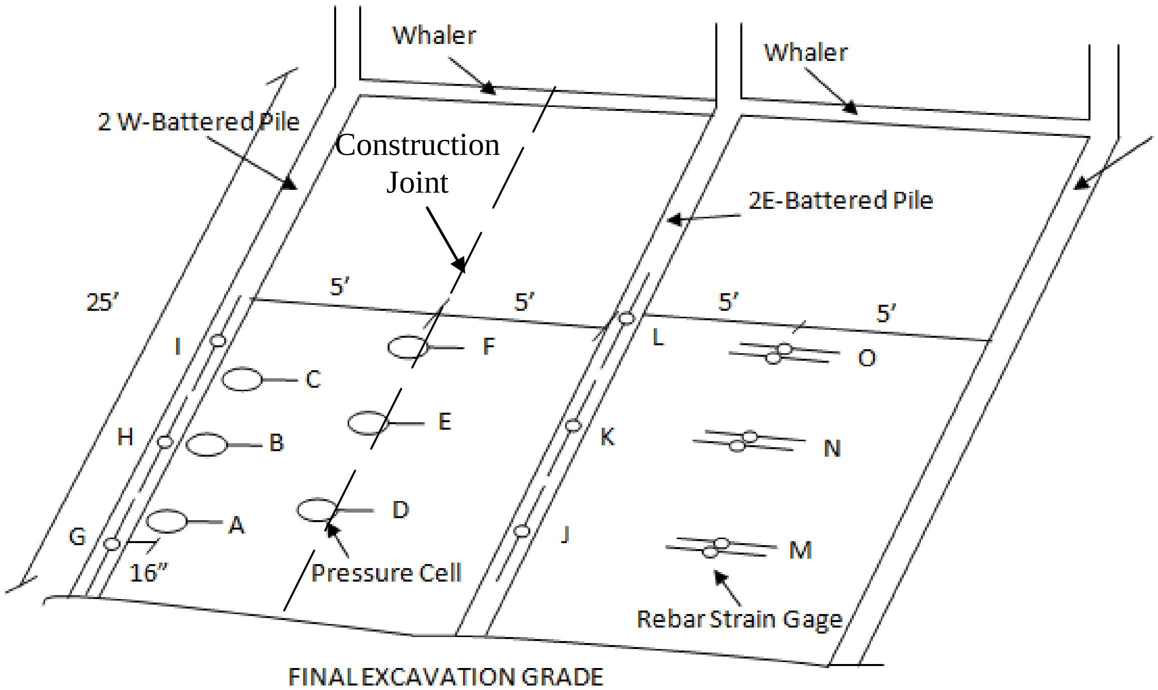
*Height is measured from final excavation grade
*Drawing not to scale



Label	Name	*Height
G	1 CSG w 5, 1 CSG w 10	6'-6"
H	1 CSG w 15	12'
I	1 CSG c 5, 1CSG c 20	5'
J	1 CSG c 10, 1 CSG w 20	10'-8"
K	1 CSG c 15, 1 CSG e 20	15'-8"
L	1 CSG e 5	7'
M	1 CSG e 10	12'-7"
N	1 CSG e 15	17'-6"

*Height is measured from final excavation grade
*Drawing not to scale

Figure 2-6. Section 1 Earth Pressure Cell and Rebar Strain Gage Layout



Label	Name	*Height
A	EP 2 e 3	4′-10″
B	EP 2 e 6	8′
C	EP 2 e 10	10′-4″
D	EP 2 c 4	5′-1″
E	EP 2 c 8	9′-4″
F	EP 2 c 12	13′-5″
G	1 CSG w 5	4′
H	1 CSG w 10	9′
I	1 CSG w 15	14′
J	1 CSG e 5	5′
K	1 CSG e 10	10′
L	1 CSG e 15	15′
M	1 CSG c 5, 1 CSG c 10	5′
N	1 CSG c 15, 1 CSG e 20	9′-3″
O	1 CSG c 20, 1 CSG w 20	13′-4″

*Height is measured from final excavation grade
*Drawing not to scale

Figure 2-7. Section 2 Earth Pressure Cell and Rebar Strain Gage Layout

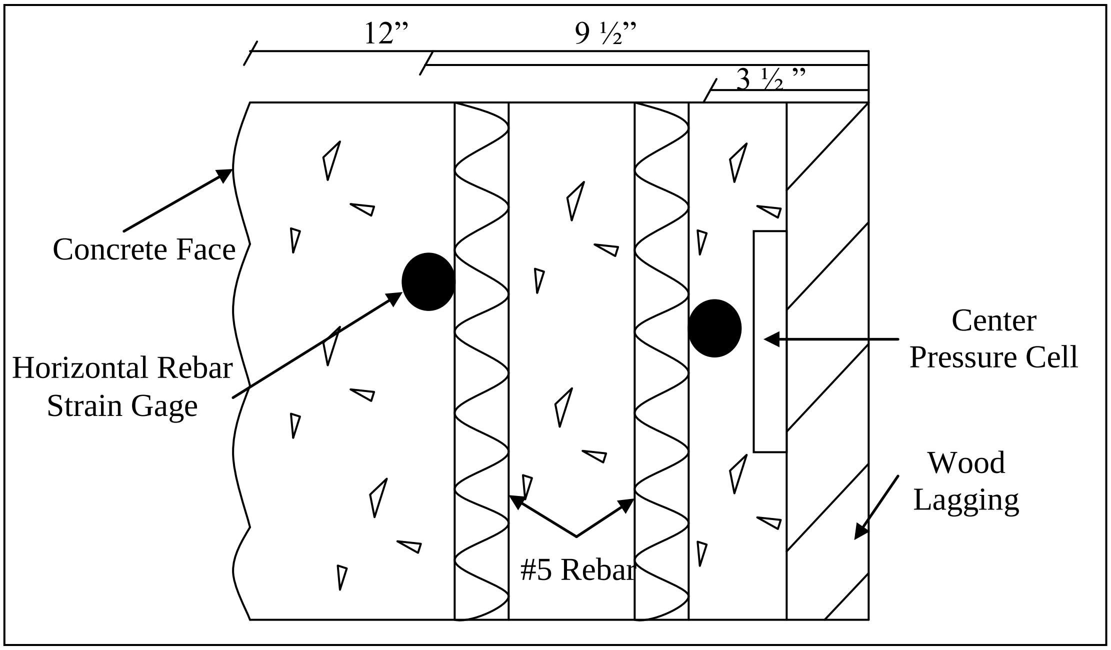


Figure 2-8. Cross Section Detail at the center of Test Section

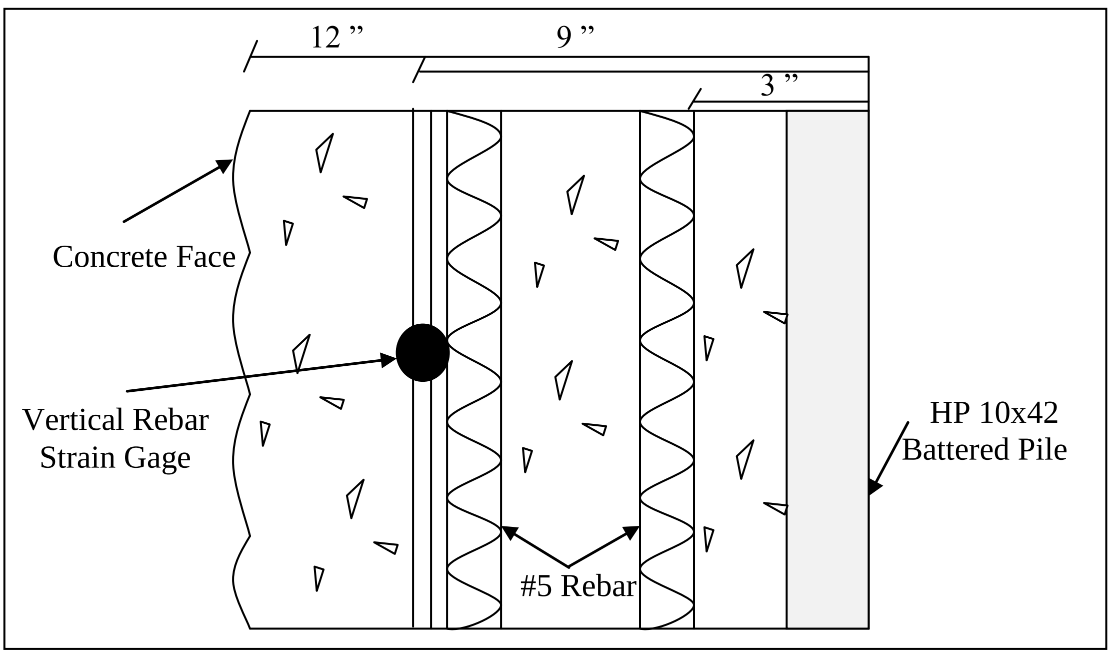


Figure 2-9. Cross Section Detail at the Battered Pile of Test Section

9 show a cross section view. The earth pressure cells were installed on the outside of the wood lagging at the bottom portion of the wall where analysis showed high levels of pressure. Three pressure cells were installed in the center of each instrumented section and three at the edge of the instrumented section in order to determine if the earth pressures acted uniformly across the two sections. The center pressure cells were placed in approximate five foot increments from the bottom and the pressure cells on the ends of the sections were installed in approximate four foot increments.

2.5 Rebar Strain Gages

The strain that the concrete face of the wall undergoes is measured by the Geokon Model 4911 Rebar Strain Gages. The rebar strain gage is a 4 ½ foot - #4 rebar with a vibrating gage sensor attached in the middle. The rebar strain gage is tied alongside the steel reinforcement for the concrete. When concrete is poured over the section the rebar is put under the same strain as the reinforcement and strain is measured using the vibrating wire technology.

In the center between the two battered piles there are three pairs of rebar strain gages installed horizontally in five foot increments. Within the pair, one strain gage is tied to the outside of the top reinforcement layer and the other to the inside of the bottom reinforcement layer. Three individual rebar strain gages are tied vertically to the outside reinforcement layer over the two battered piles. Similar to the earth pressure cells, the rebar strain gage locations are also based on finite element analyses. (Branch 2007)

2.6 Inclinometers

The displacement of the soil behind the retaining wall is determined using the Model 6000 Inclinometer Probe and the Digitilt DataMate II. The inclinometer probe is attached to a cable at one end and a rubber cap at the other end for protection. With the cable attached, the probe is lowered to the bottom of the inclinometer casing. The probe is then pulled up in half meter increments and read by the Digitit DataMate II. The displacement of the soil over time is measured by comparing the change in inclination of the inclinometer casing to its original location. Three inclinometer casings are installed on three points behind the retaining wall; one behind each analyzed section and one at the high point of the wall.

Chapter 3: Data Collection

3.1 Acquiring Data

Data collection began with the strain gage instrument installation. The first set of data was read in August 2007 before the piles were driven in order to ensure that the instruments were operating correctly and preset to proper values. Once the piles of each section were driven, a set of strain gage readings were read and compared to the installation readings that contained no loads. Strain gage readings were then read after each excavation lift on the retaining wall. During the construction phase, all strain gage data was stored in the GK 403 Readout Box and exported to an Excel worksheet.

The load cell data was collected after each anchor was pre-loaded with 50 kips of force. Data read on the Geokon GK 403 Readout Box was unable to be stored because of the setup of the load cells. Three sensors on the load cell must be read on the first three reference numbers of the box. Since these reference numbers were already assigned to a strain gage, each load cell reading was manually collected in a notebook and then transferred to an Excel worksheet.

The pressure cells and rebar strain gages were installed after excavation was complete and readings were immediately taken as the instruments experienced no load. After final grade was reached the concrete face of the wall was poured, and the concrete cap was poured, data from all instruments installed on the retaining wall were collected consistently every few weeks. Tables A-1 and A-2 in Appendix A.2 break down the data collection of each instrument and show the assigned project day. This thesis includes data collected through May 2009.

3.2 Analyzing Data

Data analysis of each section was compared to the initial set value of each section. The initial set value for the strain gages are the average of all data collected before concrete was poured on the face of the retaining wall. The initial set value for the earth pressure cells and rebar strain gages are based on no load readings from the field. Even though strain is measured for each instrument, all devices required a different setup for analysis. Each setup is described in the sections to follow.

3.2.1 Strain Gages

The strain gage instruments are used to find a strain reading on the pile in order to obtain a stress at a given point. Two separate analyses were used in reducing the strain gage data for the vertical and battered piles. The vertical piles consisted of a least square fit calculation where the coordinates, see Figure 2-2, of the strain gage locations are used. Stress values from the four strain gages are determined using Equation 3-1 and are entered in order to solve the simultaneous equations, Equation 3-2.

$$\sigma(ksi) = E \times \varepsilon = 29{,}000 ksi \times \varepsilon \times 10^{-6} \qquad \text{EQ 3-1}$$

$$\begin{aligned}
\frac{P}{A} + \frac{M_x}{I_x} y_1 + \frac{M_y}{I_y} x_1 &= \sigma_1 \\
\frac{P}{A} + \frac{M_x}{I_x} y_2 + \frac{M_y}{I_y} x_2 &= \sigma_2 \\
\frac{P}{A} + \frac{M_x}{I_x} y_3 + \frac{M_y}{I_y} x_3 &= \sigma_3 \\
\frac{P}{A} + \frac{M_x}{I_x} y_4 + \frac{M_y}{I_y} x_4 &= \sigma_4
\end{aligned} \qquad \text{EQ 3-2}$$

Once these equations are solved for a value for the stress and moments can be found using the steel section properties and verified using Equation 3-3.

$$\sigma = \frac{P}{A} + \frac{M_x y}{I_x} + \frac{M_y x}{I_y} \qquad \text{EQ 3-3}$$

The battered pile data contains forces from the steel and the concrete face. The vertical rebar strain gages are used with the strain gages to reduce the data. Least square fit calculations find the strain in the extreme fibers. Forces and moments are determined using strain compatibility and the compression or tension state of the concrete.

3.2.2 Load Cells

The load cell data was manually collected and exported to an Excel worksheet. The data is converted into a applied load by comparing the initial reading to the current reading of the selected day. The three sensors are averaged together and used as the current reading. Equation 3-4 and 3-5 from the Geokon manual show the equations for calculating load.

Load = Gage Factor * (Zero Reading-Current Reading) EQ 3-4

Temp. Corrected Load = Load – K*(Initial Temp.-Current Temp.) EQ 3-5

The temperature corrected load equation (EQ 3-5) is used in the analysis to account for temperature changes within the device, where K represents the thermal factor. This load value, in the units of kips, shows the amount of tensile force that the anchor rods experience with time. With load values from selected dates, a graph can be created that shows the change in loads over time. Section 4.2 explains the results of the anchor loads.

3.2.3 Pressure Cells

The earth pressure cell data was stored in the GK 403 Readout Box during the construction phase and exported to an excel worksheet. In order to acquire pressure from the readings Equation 3-6 from the Geokon manual was used to find pressure in units of pounds per square foot.

$$\text{Pressure} = ((\text{Initial Reading} - \text{Current Reading}) * \text{Gage Factor}) + ((\text{Current Temp.} - \text{Initial Temp.}) * \text{Thermal Factor}) \qquad \text{EQ 3-6}$$

Each earth pressure cell data has its own gage and thermal factor that is used to determine pressure with a reading from a selected day. The earth pressure cells are extremely sensitive to temperature and on the day of installation of Section 1, the temperature of the pressure cell in the direct sunlight reached 100 ºF. Since a high temperature showed a false initial reading, the average of the low and high readings were set as the initial readings, Figure 3-1.

During the installation of Section 2 pressure cells, temperatures were not excessively high. Therefore, the initial readings were simply set as the no load readings in the field. After initial readings were determined, the pressure was calculated for each earth pressure cell. These values, in the units of pounds per square foot, show the amount of pressure that the soil is pushing against the wall. With pressure values from selected dates, a graph can be created that shows the change in pressure over time. Section 4.3 explains the results of the earth pressure cells.

3.2.4 Rebar Strain Gages

The rebar strain gage data was also stored in the GK 403 Readout Box during the construction phase and exported to an excel worksheet. In order to acquire strain from the readings Equation 3-7 from the Geokon manual was used to find strain.

$$\text{Strain} = (\text{Current Reading} - \text{Initial Reading}) * \text{Gage Factor} \qquad \text{EQ 3-7}$$

Once strain is calculated, the stress and uniform pressure that the concrete face undergoes is determined using the results from the horizontal rebar pairs. In order to account for the different strain values and planes from the two horizontal rebar strain gages, the slope of the pair is used to calculate stress values. The modulus of elasticity for the concrete is used as 3600 ksi and no stress values exceed the modulus of rupture. Once stress values are found for each rebar strain gage, they are averaged and multiplied to the width of the section and thickness of the concrete to find the load. The vertical rebar strain gage results are used in determining results for the forces in the battered pile, see Section 3.2.1. Section 4.4 explains the results of the strain in the concrete.

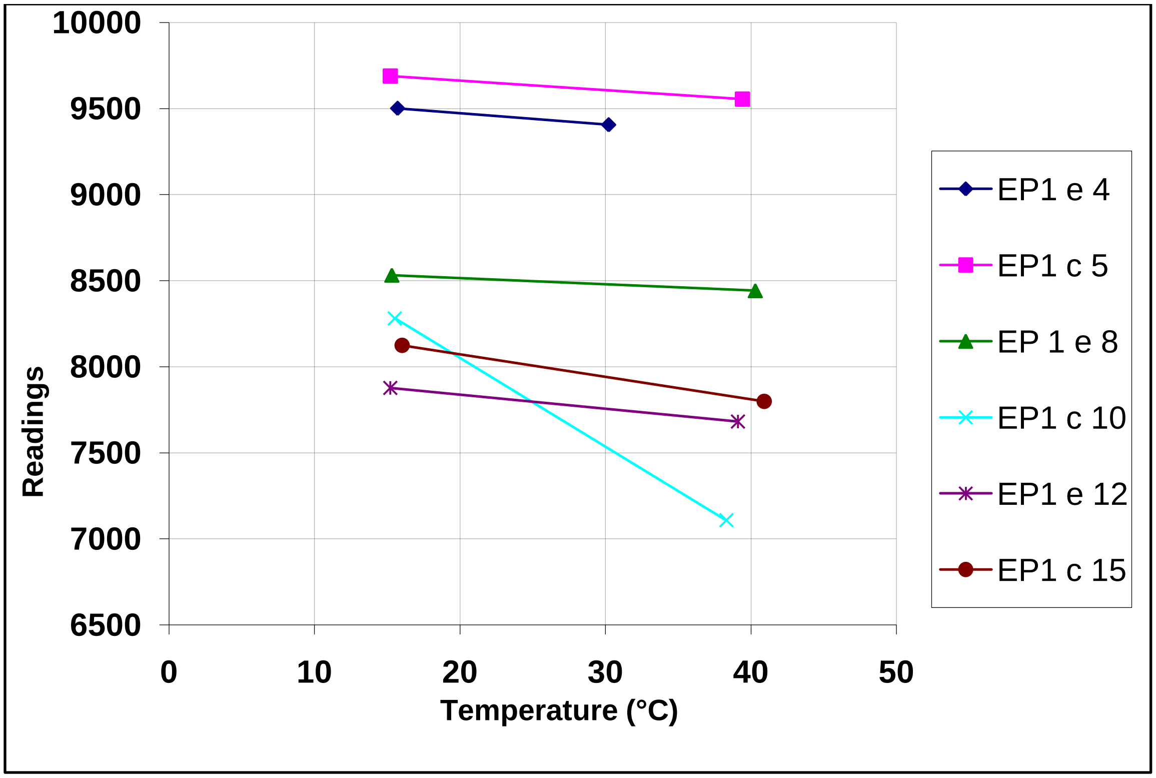


Figure 3-1. Section 1 Earth Pressure Cell Initial Readings with Two Points

3.2.5 Inclinometers

Data from the inclinometer instrument is collected using the Digitilt DataMate II. Once readings are recorded in the device, the data is opened with the DMM for Windows software which displays each day's readings versus depth in a table. The program also creates graphs that are used to evaluate the displacement over time. The DigiPro for Windows software is also used to analyze data. With this program, all selected days of data can be placed on one graph for comparison of displacement over time. Section 4.5 explains the results of the lateral movement of the wall.

3.3 Data Acquisition System

Data after the wall was fully completed was stored in the Campbell Scientific data acquisition system. Wires from all instruments were connected to a series of multiplexers. Programs were sent to the automated system that allowed strain outputs to be stored based on frequency settings. Similar to the GK 403 readout box, the data acquisition system performed the same calculations, but obtains strain readings each day without the physical and timely exertion on the operator. A data chip is taken from the device and converted to an excel format using the LoggerNet software that accompanied the system.

Chapter 4: Results

4.1 Strain Gages

A total of 180 strain gages are wired to the two test sections. At the conclusion of this research 12 gages were not operational, nine from Section 1 and three from Section 2. The results of all strain gages are referenced to the day after the face of the concrete was poured. All readings taken before this point showed small variations due to the low activity or loading of the wall. Therefore, this data has been averaged and assumed as an initial reading for analysis.

Stress versus time was evaluated for each set of four strain gages on the piles to check the consistency of the data. Figure 4-1 shows the stress versus time graphs for the east vertical pile of Section 2 .The stress data from the pile show a decrease in stress (compression) several months following the concrete cap and face pour over the section. The stress values then slightly increase over time. The compressive stress values can be attributed to the piles initially bearing some of the weight and experiencing the bending of the concrete and then relaxing over time. The majority of the readings for each research test pile follows a similar trend and show uniform change in strain that each gage undergoes. The stress values show low results throughout the research period and don not come close to the 50 ksi yield strength, as expected.

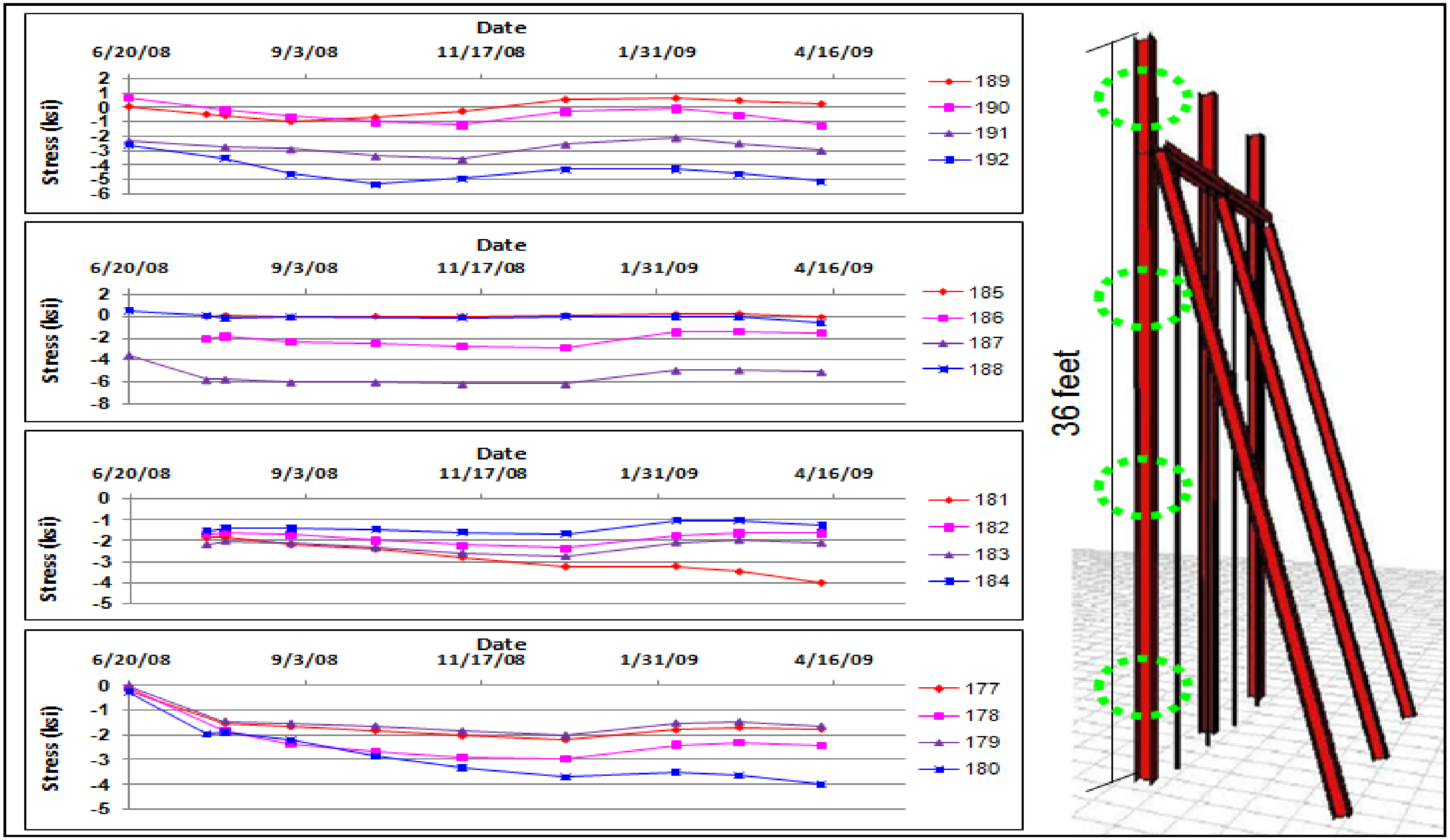


Figure 4-1. Time vs. Readings for Section 2 East Vertical Pile

4.1.1 Vertical and Battered Pile

Loads and moments that build up on the vertical piles are found using the equations from section 3.2.1. Figures 4-2 and 4-3 show the load results for vertical piles from Section 1 where zero depth is considered to be the top of the pile. The results from both piles show mostly negative readings which indicate a compressive force on the steel pile. The east pile is more than twice the length of the west pile due to the soil conditions on the site. When the permanent vertical pile was driven, the tip of the east pile hit the side of rock which caused the bottom of the pile to bend toward the anchor rod. As a result, the two piles experience different forces at similar locations despite being only ten feet apart.

Looking at the west pile, the first set of strain gages is located on the first two feet of the pile. This portion of the pile was located above ground until the concrete parapet was poured and the soil was backfilled. The location seems to play a role in the steady increase of load of approximately 60 kips that occurs after the parapet pour date. As you travel down the pile in the soil that was originally retained, there are fewer variations with load over time. The small variation indicates that the force remains the same throughout the vertical pile, as expected.

The east pile of Section 1 extends 62 feet and shows a wide variance in load. Between each set of strain gages the load swings from a high to low value of compressive force with variations occurring at 20 feet lengths. The extreme shifts in forces are due to the bent tip of the pile. As load is transferred to the pile, the upper portion of the pile is

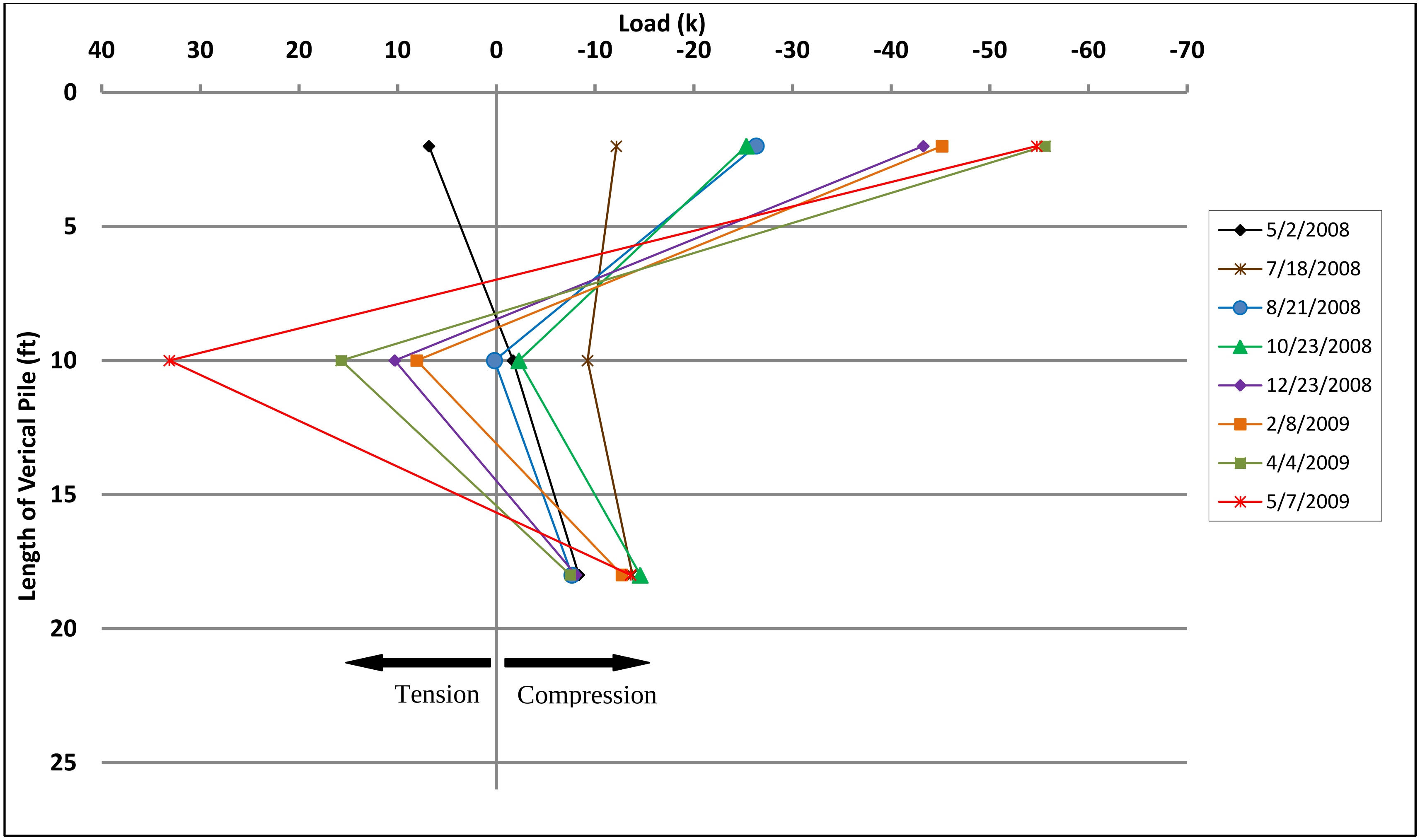


Figure 4-2. Section 1W Vertical Pile Load Results

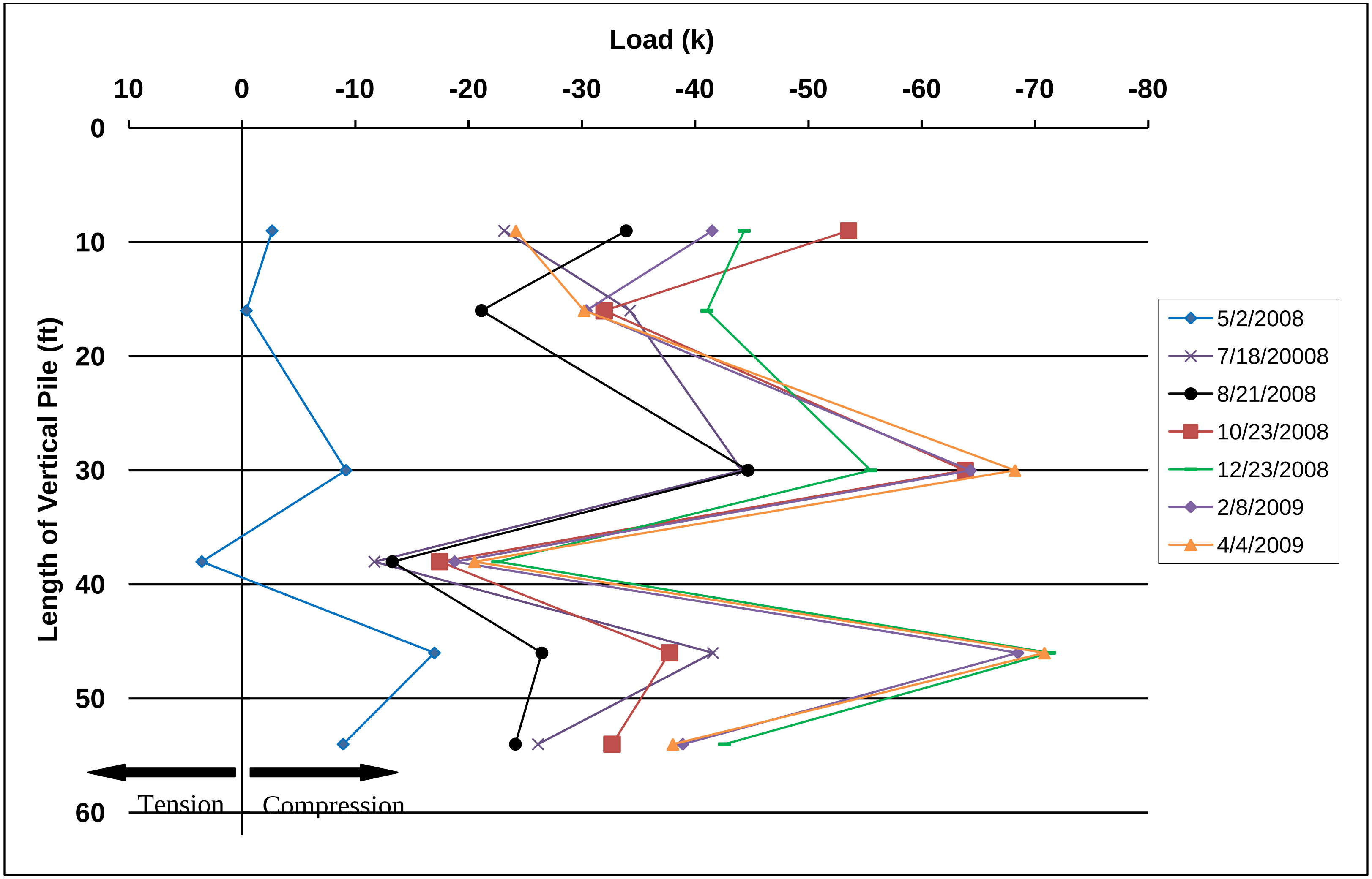


Figure 4-3. Section 1E Vertical Pile Load Results

compressed and experiences the bulk of the load. When load reaches the point of the bend, which rests on rock, less compression force occurs.

Moments were also calculated for the vertical piles in the strong and weak axis. Figure 2-2 shows the location of the two axes on the piles. Due to the locations the strong axis bending, x-axis, results are more of interest in determining the behavior of the retaining wall. Figures 4-4 and 4-5 show the results from the west and east pile of Section 1. Both piles contain positive and negative moments where a positive moment indicates tension on the inside face of the wall that is closest to the soil and a negative moment represents the opposite. The positive moment regularly occurs at the top of the pile, and the negative moment occurs in the middle of the pile, consistently. The moment results from Section 2 are in B.2 of the Appendix

Loads and moments that build up on the battered piles are analyzed using the composite section method. Figures 4-6 and 4-7 show the load results from Section 1. Since the composite section includes strain results from the rebar strain gages, only the bottom half of the battered pile is analyzed where the rebar strain gages were installed because the entire composite section had to be included in the calculations. Positive loads indicate a compressive force.

Load results from the west pile of Section 1 show inconsistent results over time. Unlike the typical results, it does not continue to follow a trend over time. Only one gage is not operational, the construction of the wall is complete, and no significant construction events are occurring near the wall. Causes for the shifts seem to be slight compressive changes in the rebar strain gages over time. The east pile does follow

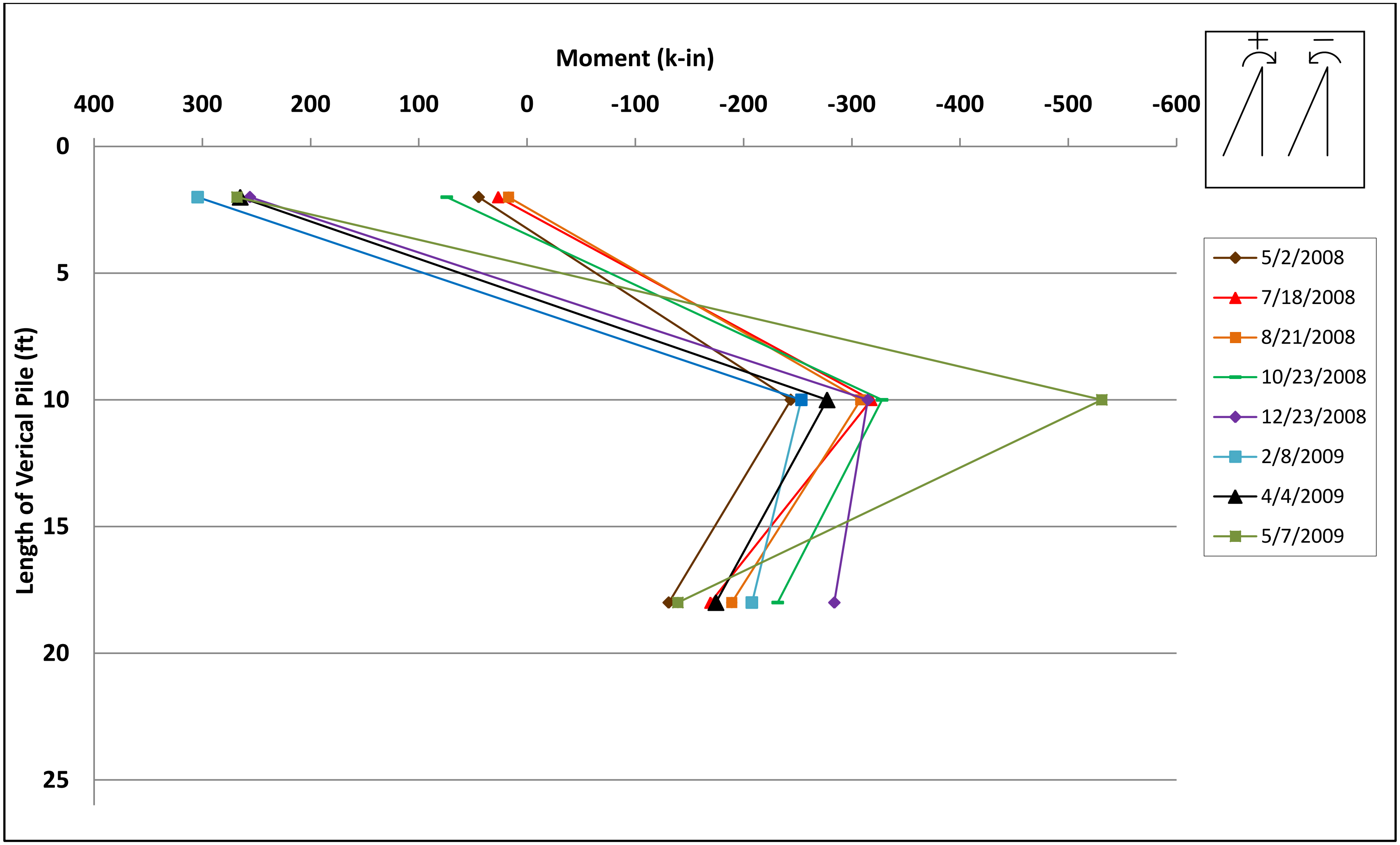


Figure 4-4. Section 1W Vertical Pile Moment Results (strong axis)

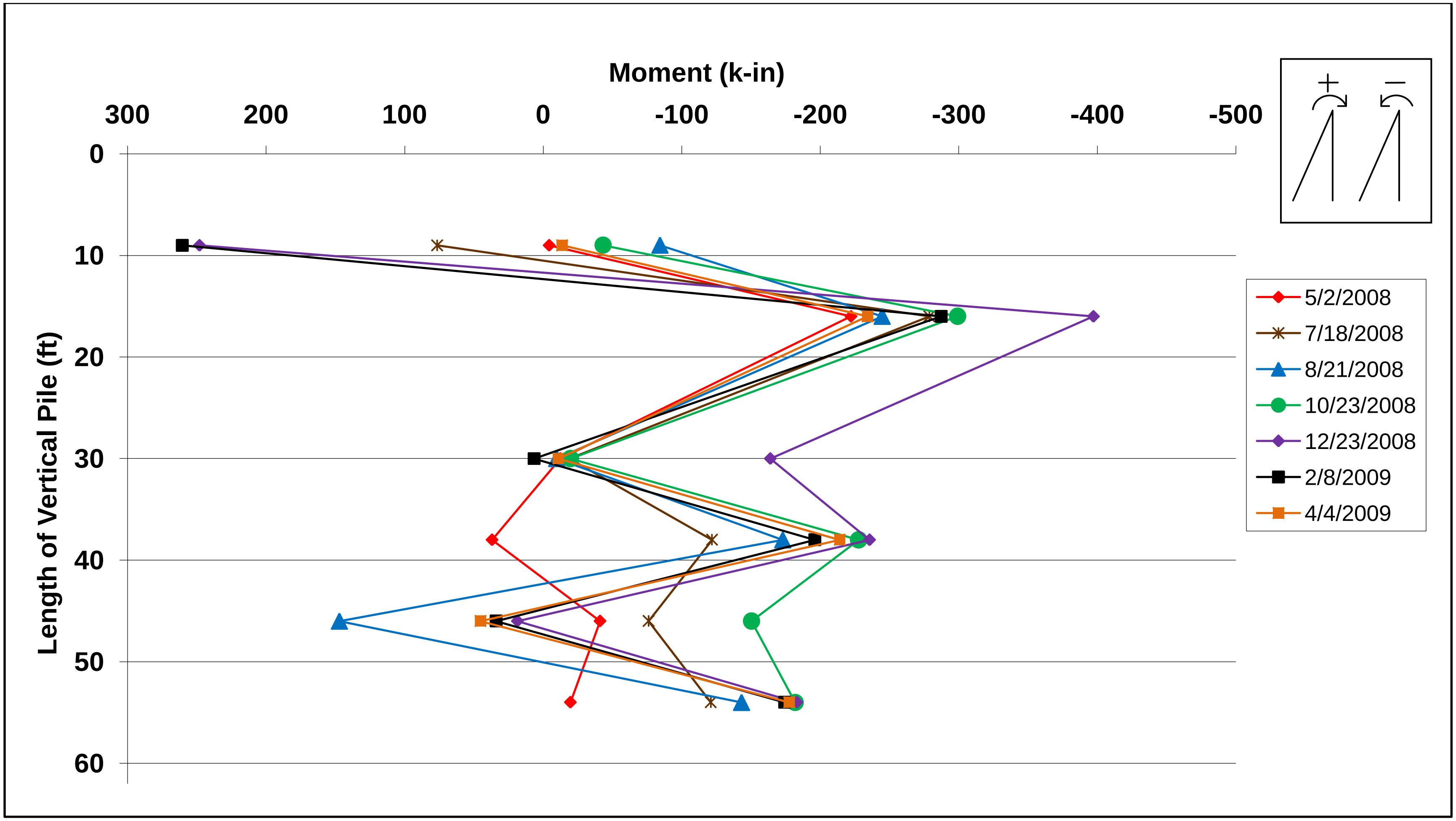


Figure 4-5. Section 1E Vertical Pile Moment Results (strong axis)

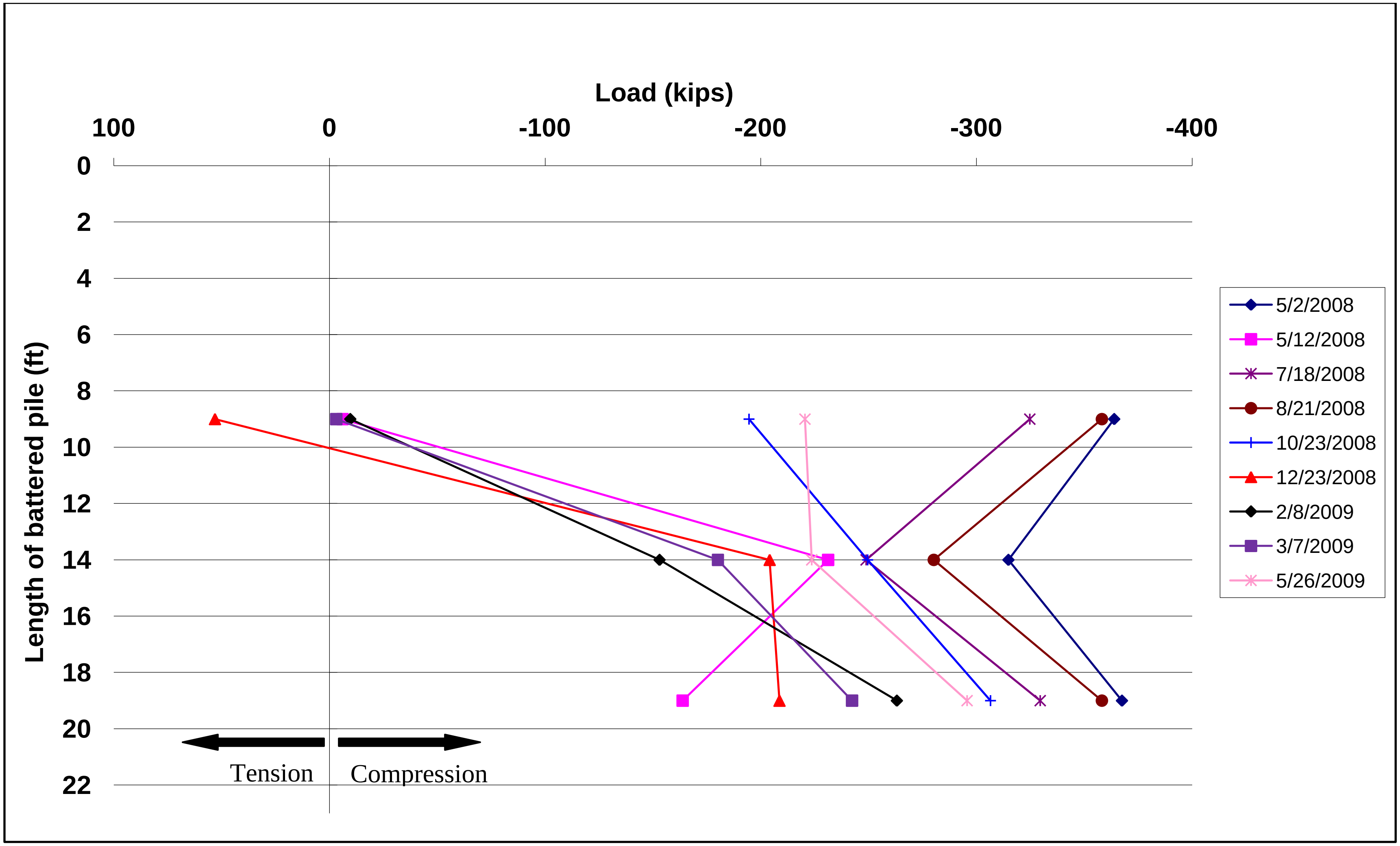


Figure 4-6. Section 1W Battered Pile Load Results

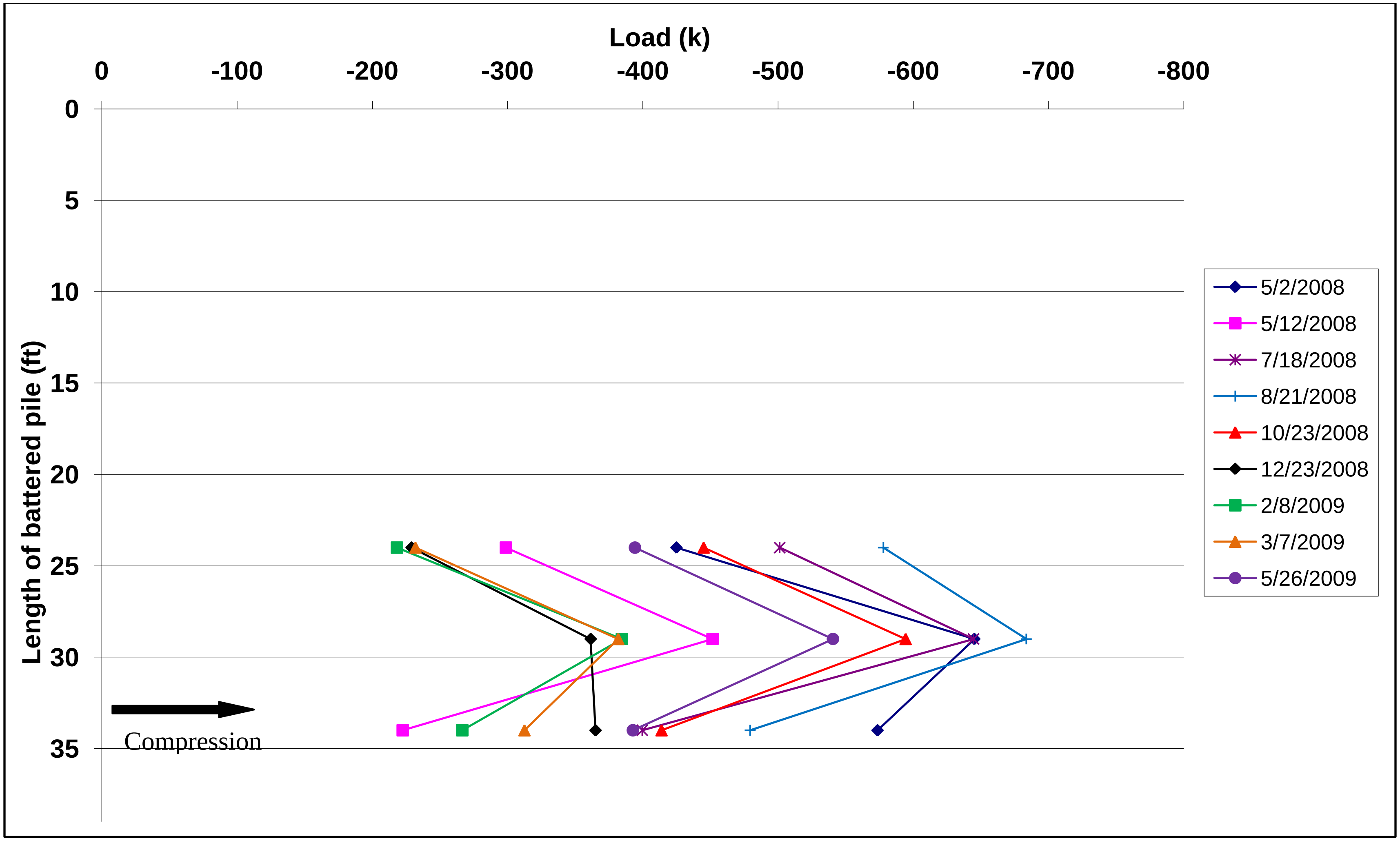


Figure 4-7. Section 1E Battered Pile Load Results

the typical pattern results. Similar to the vertical piles of Section 1, the battered piles relax over time and slowly loses the high compressive force that was caused by the weight of the concrete. Both piles of Section 2 have similar results to the east pile of Section 1. The pile results of Section 2 are shown in B.3 of the Appendix.

Bending in the Section 1 battered piles shows a consistent result over time. The west and east piles, Figures 4-8 and 4-9, show positive moments. Over time the moment values increase, with the largest value occurring approximately 10 ft above the tip of each battered pile. The results of Section 2 also show a positive moment values, but the increase in moment values differ. The west pile show a higher moment value occurring approximately 15 ft above the tip of the battered pile which is close to the center. Values occurring 5 ft and 10 ft from the pile have very similar results. However, the east pile of Section 2 show more change near the bottom of the pile. Section 2 graphs are shown in B.3 of the Appendix. Both section battered pile moment results correlate with the change in force. As the force becomes more compressive, the moment values become more positive, and vice versa. The moment results verify the assumed bending behavior of the pile when bearing a load.

4.2 Anchor Loads

Forces on the anchor loads are measured by load cell instruments that surround the anchor. Calculations are referenced immediately after the anchors were pre-stressed to 50 kips, rather than after the concrete face was poured. Figures 4-10 and 4-11 show the anchor load results for Section 1 and 2.

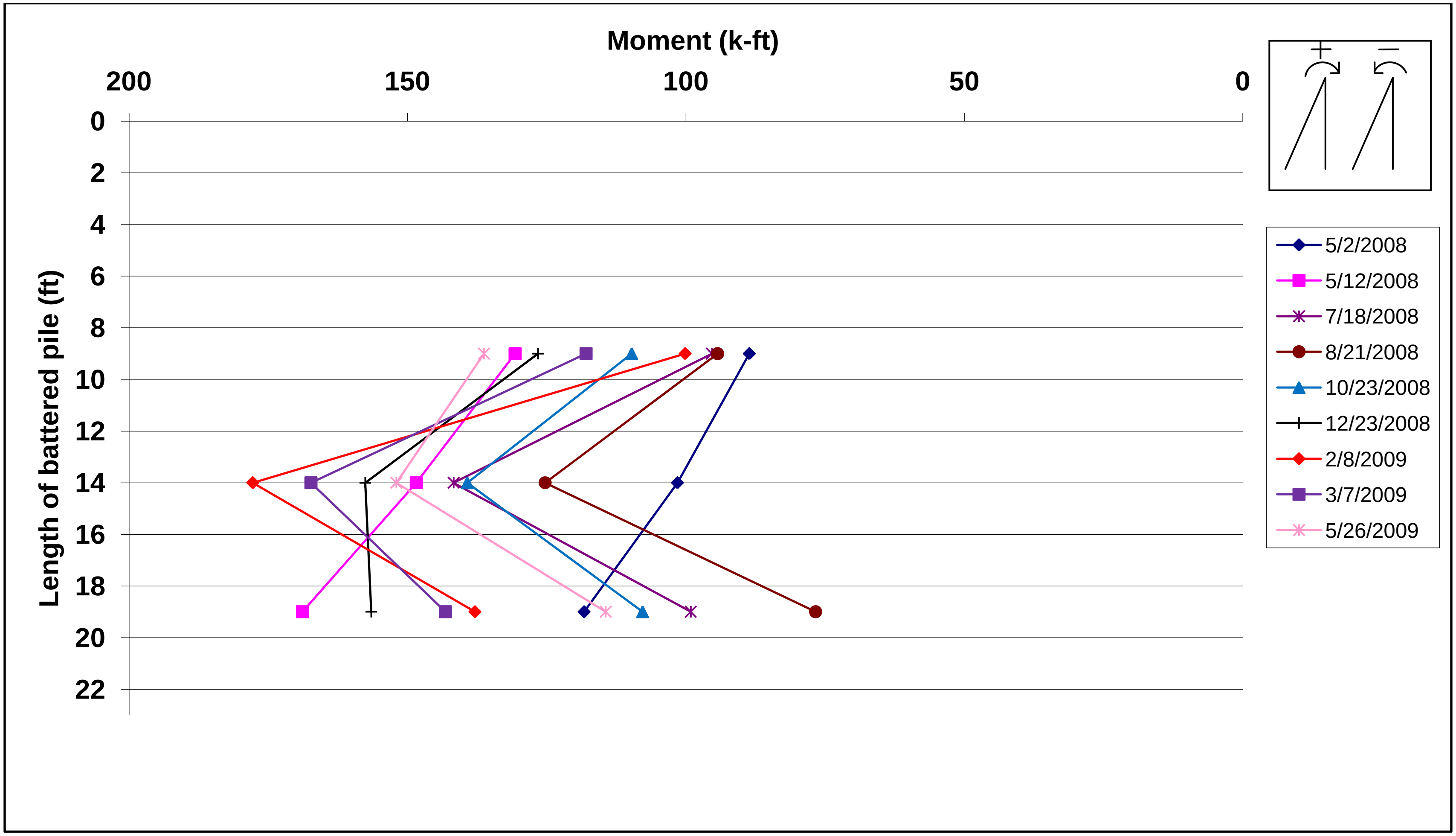


Figure 4-8. Section 1W Battered Pile Moment Results

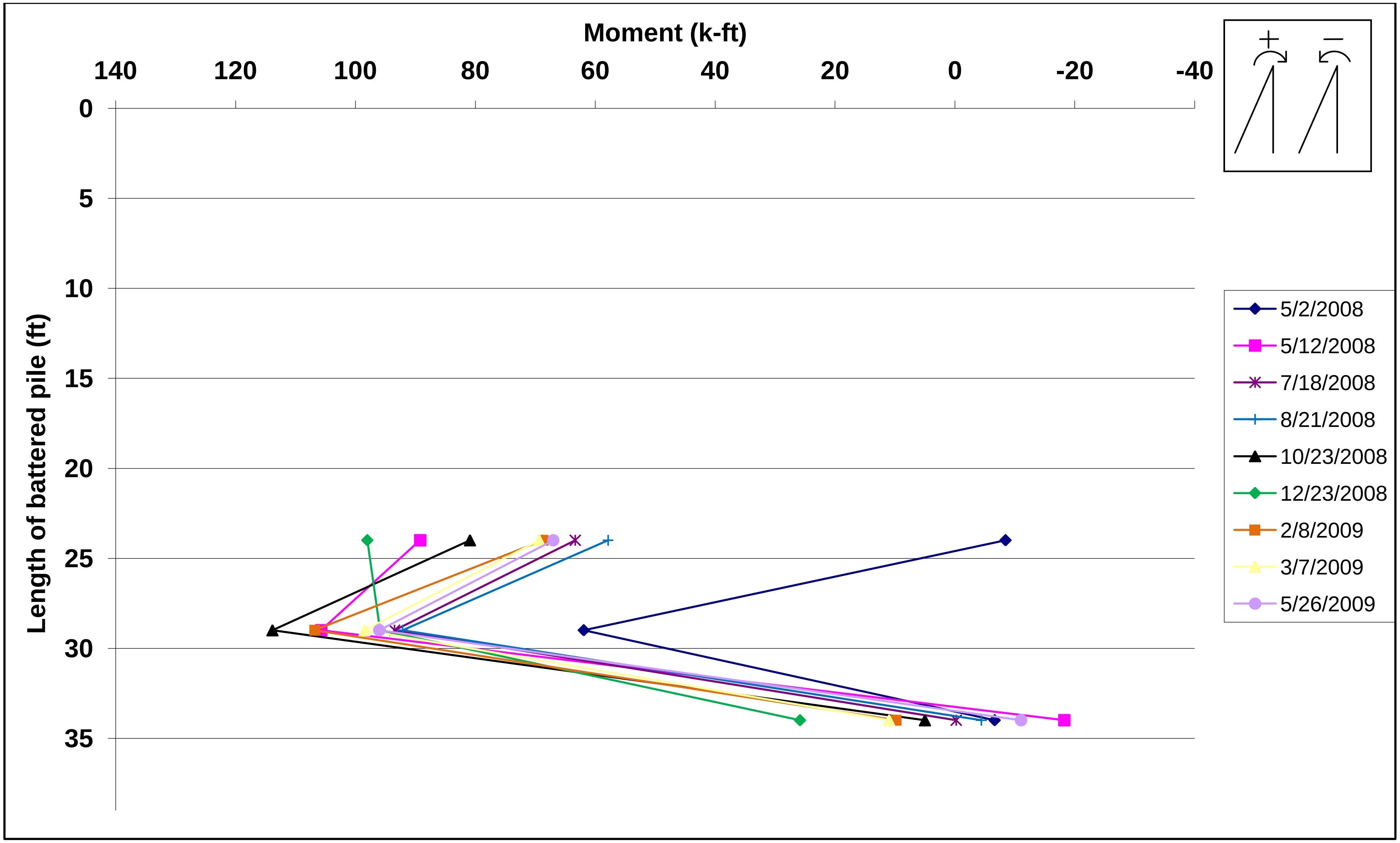


Figure 4-9. Section 1E Battered Pile Moment Results

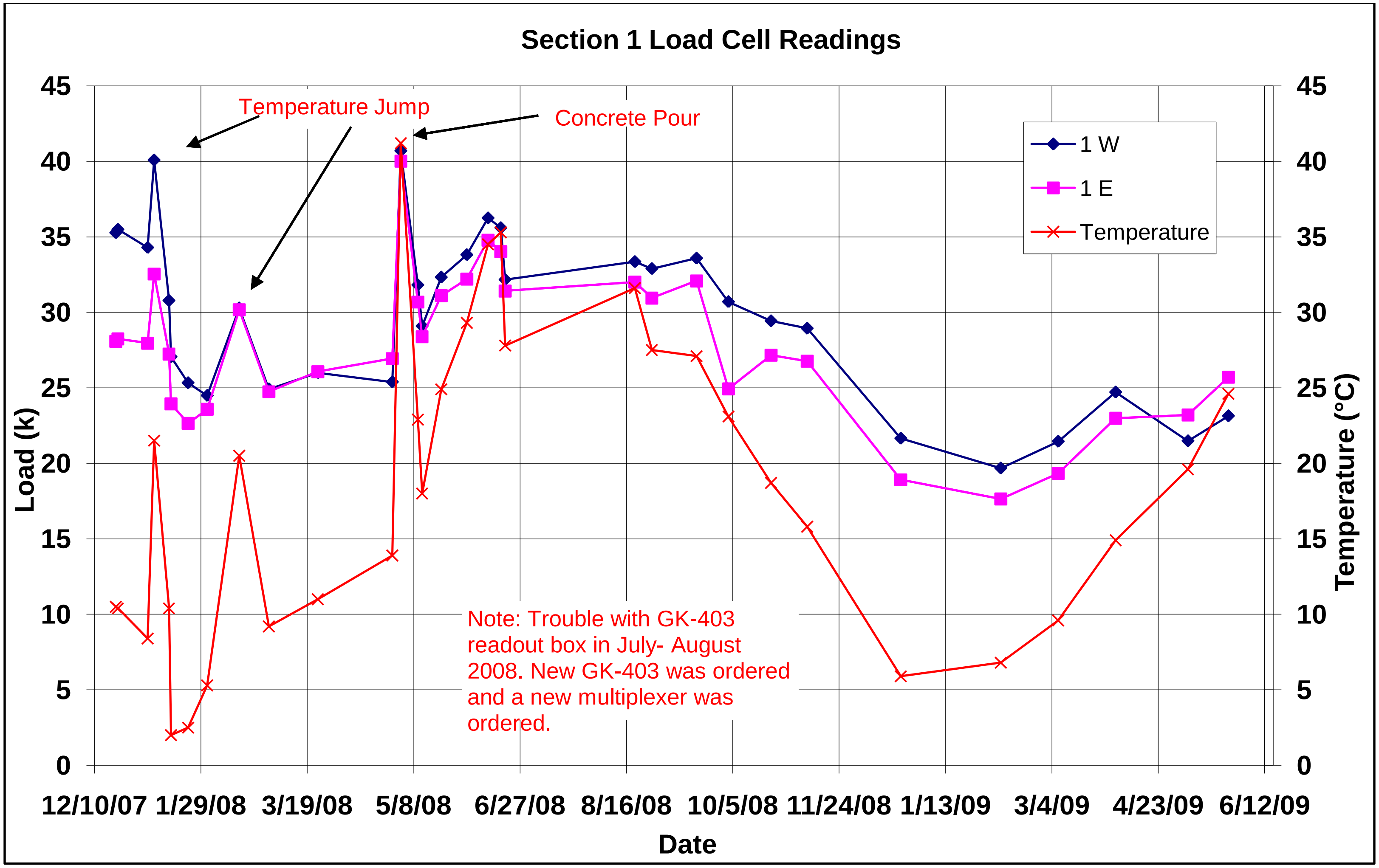


Figure 4-10. Section 1 Load Cell Results

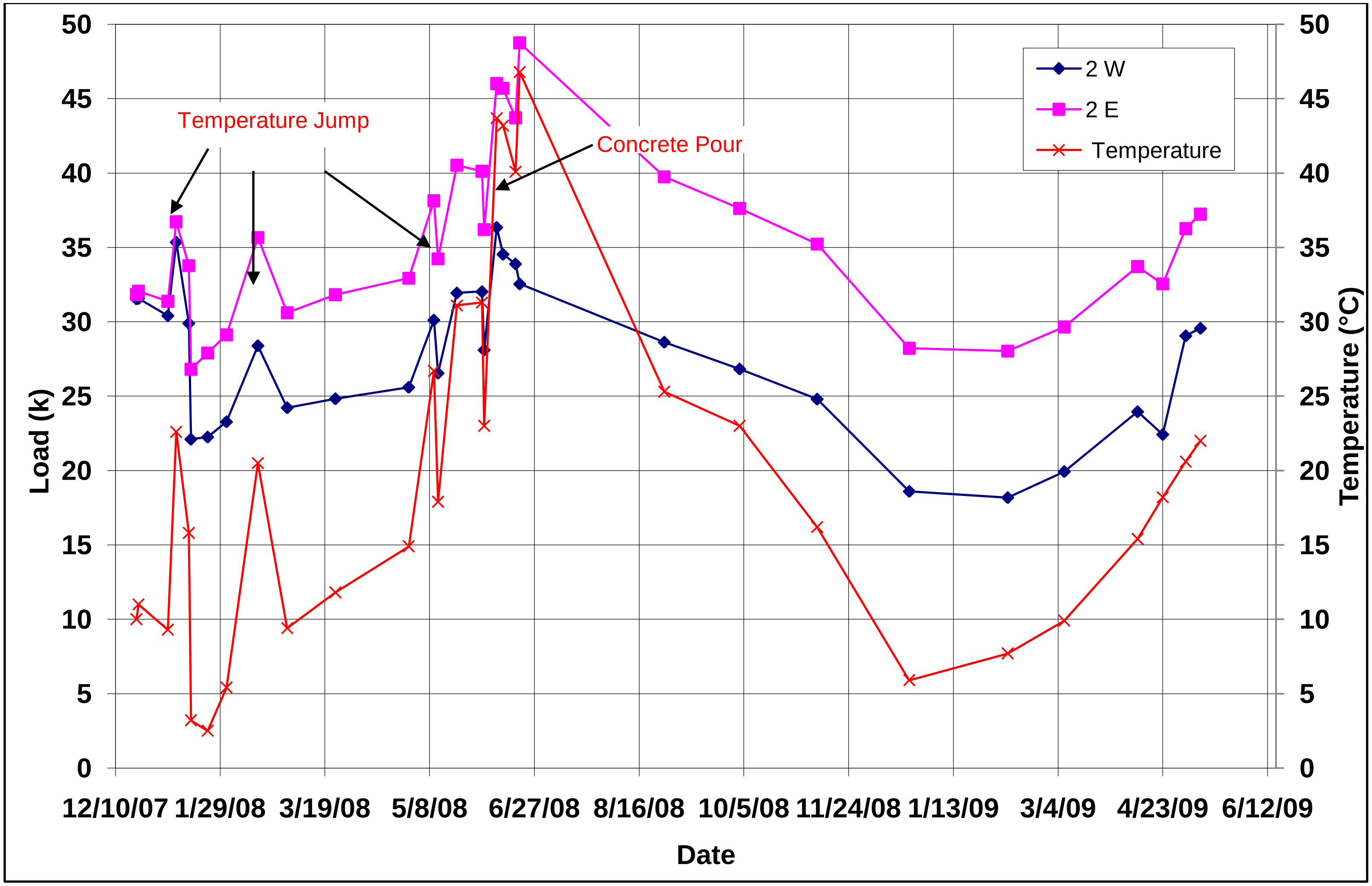


Figure 4-11. Section 2 Load Cell Results

Section 1 results for initial loadings for the anchors show loadings of 28 and 35 kips and never reach the design 50 kip load during the research period. A noticeable change in loading occurs with temperature changes within the load cell. As the weather suddenly heats up or the high temperatures of the concrete pour take place, a high increase in load is seen. The season also affects the load. During the cold months a steady drop is noticed, and as the months become warmer, the results slowly begin to increase again. The two load cell have similar results are and stay within 5 kips.

Section 2 results also do not begin at 50 kips, and both instruments began at 32 kips. Temperature also affects the load readings in the same way. One major difference from Section 1 is the load cells in Section 2 were surrounded with aerosol foam to isolate them from the concrete. A barrier between the concrete and the load cells was created to limit the sharp increase readings of the concrete pour. However, readings still sharply increased despite the barrier. After the concrete face is poured over the entire section, the results of the two load cells differ greatly. The concrete face joint was located directly in the middle of Section 2, causing each load cell to experience separate forces.

The forces measured by the load cells for both sections experience similar trends with temperature. It appears that the load results over time are the direct result of temperature change because the loads begin to increase as temperatures rise. The force that the anchors support is minimal compared to the piles. This suggests that most of the load is transferred to the vertical and battered piles and not the whaler, where the anchor is located. The whaler serves more as a connection between the piles and takes on minimal loads.

4.3 Earth Pressure Cells

Soil pressure that builds up behind the wall is measured using the earth pressure cells. Pressures are monitored in the center of each section and on the edge of each section, approximately 1 ½ feet from the center of the west pile. Negative pressure results indicate compression or positive pressure due to the soil pushing against the wall. Figures 4-12 and 4-13 show the graphs of the pressure readings on Section 1. In both instances, as the time passes the pressures decrease. This result is expected due to the high temperature and pressure the concrete initially creates after being poured. The pressures monitored in the center o Section 2 can be seen in Figures 4-14 and 4-15. The decreases in these pressure results are similar to the edge readings.

Earth pressure cell data was very inconsistent during the period of research. Unlike the uniformly decreasing or increasing data that the strain gages showed, the earth pressure cell data swung from a high to low values. The earth pressure cells sensitivity to temperature tends to cause false high readings during high heat, but other questionable readings occurred during average temperature that was observed during the research. This data shift indicated that some areas of the wall are experiencing no soil contact.

Active and At Rest pressures were calculated using estimated values of internal friction angle and the unit weight of soil, 32º and 110 pcf respectively. (Branch 2007). Where compression readings are shown, the pressure values do not reach the Active and At Rest calculations. Based on these calculation, the weathered rock soil profile (Figure 1-4), and small changes in the raw pressure readings (Appendix D), it is apparent that the pressure cell readings are not picking up a significant amount of pressure from the soil

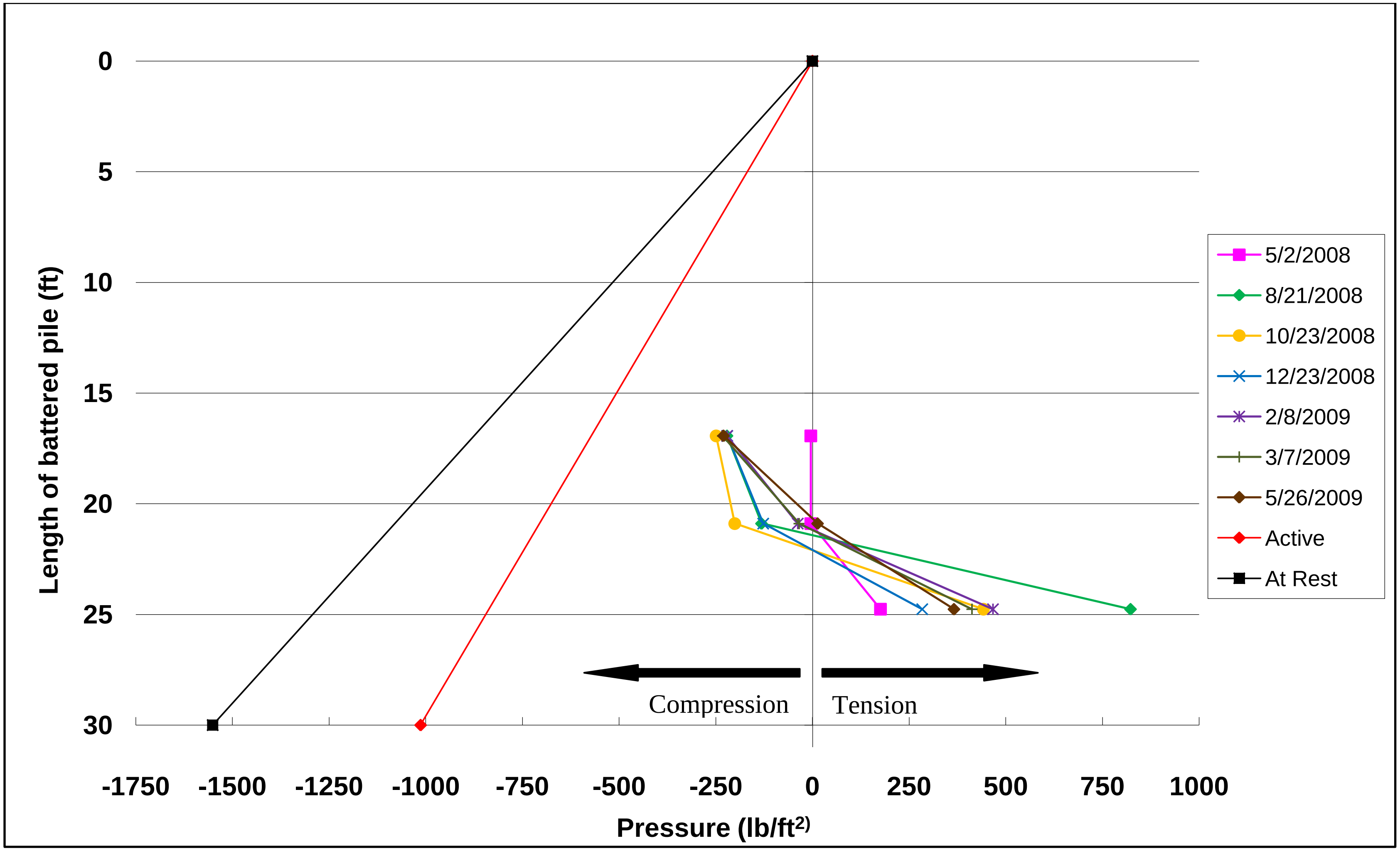


Figure 4-12. Section 1 Edge Pressure Cell Results

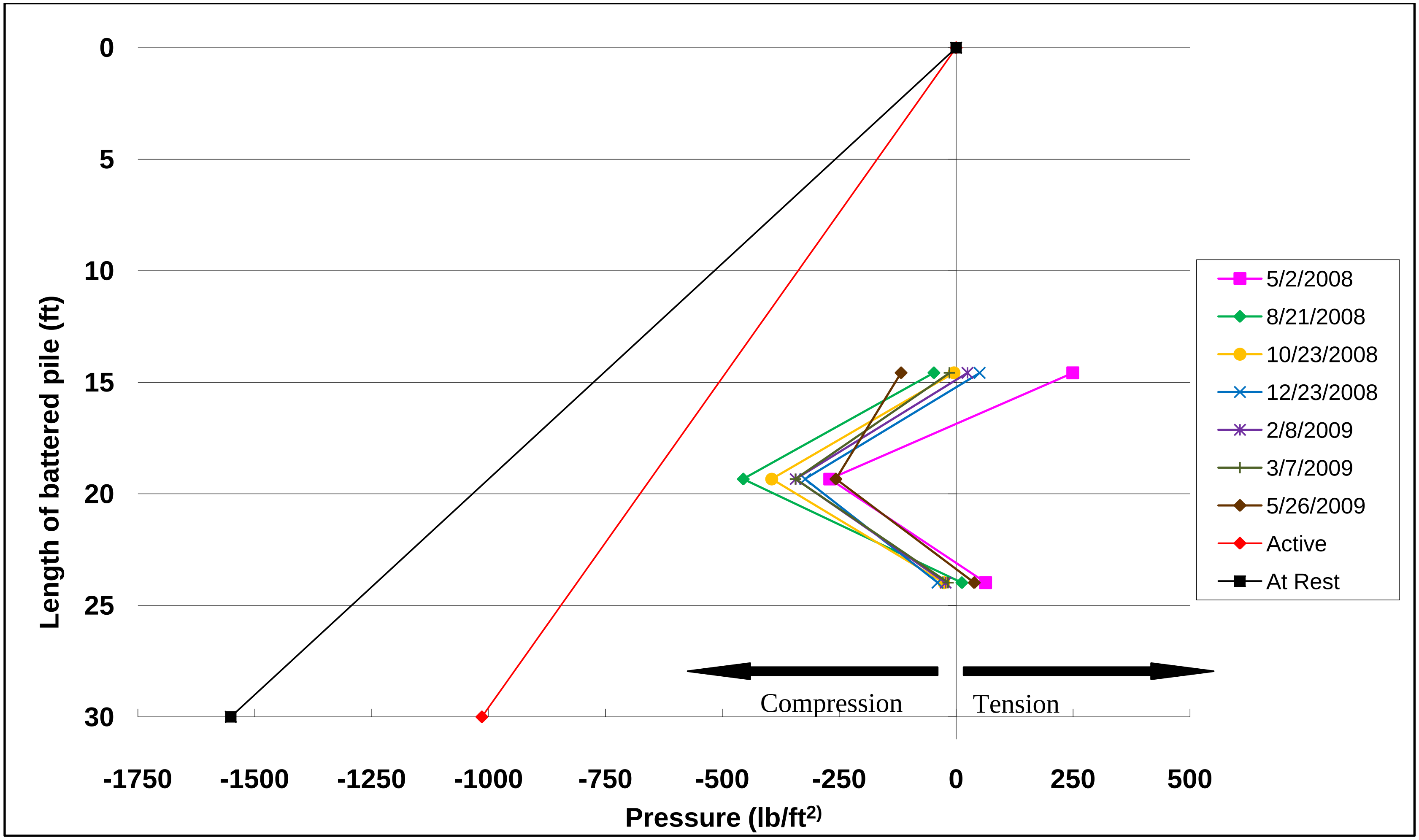


Figure 4-13. Section 1 Center Pressure Cell Results

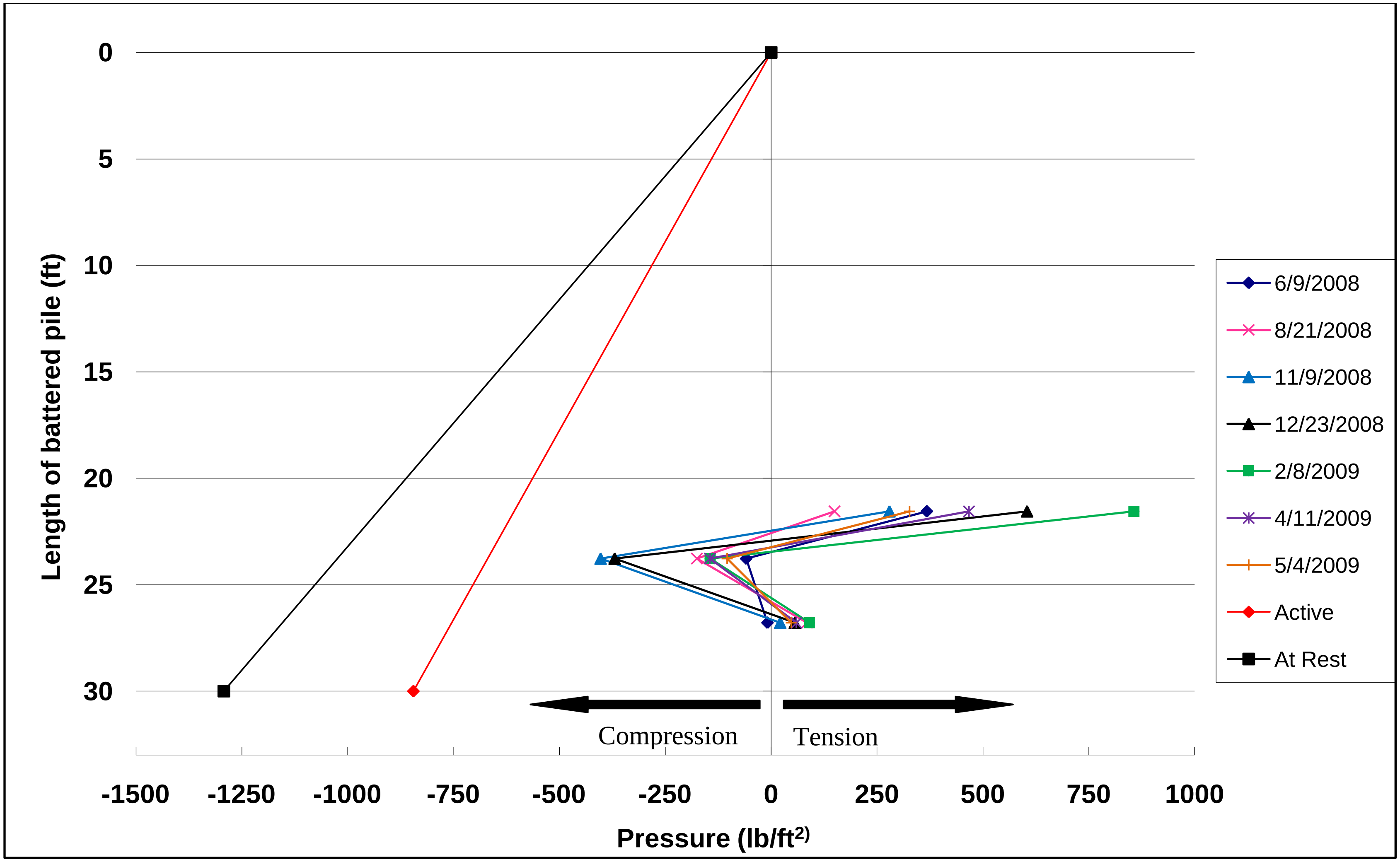


Figure 4-14. Section 2 Edge Pressure Cell Results

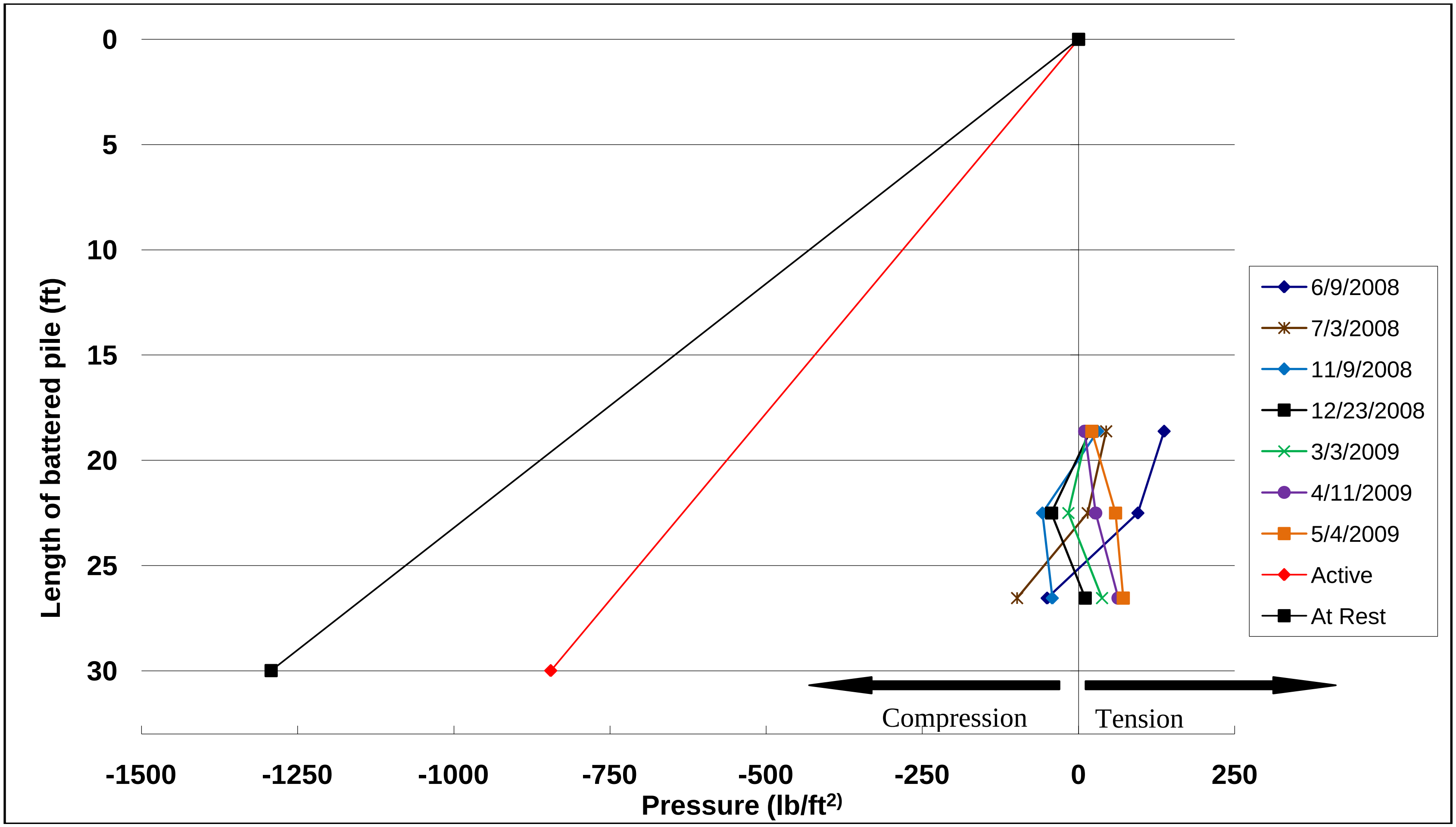


Figure 4-15. Section 2 Center Pressure Cell Results

and it can be assumed that the soil is holding itself in place and not coming in contact with the retaining wall in most areas.

4.4 Rebar Strain Gages

Rebar strain gages are used to analyze the behavior of the concrete wall face on the retaining wall. A total of 24 rebar strain gages were installed on the tie back retaining wall, 12 on each section. One rebar strain gage was not operational after the concrete face pour. The results from the rebar strain gages that were installed vertically over the battered piles are connected with the strain gages, section 4.1.1. The pairs of horizontal rebar strain gages were analyzed separately and the uniform load of the concrete in pounds per square foot were determined. Pressure values for both sections were small when compared to earth pressure cell values that showed a compression force.

The results of the Section 1 rebar strain gages showed compressive, or negative, strain measurements throughout the research period. Higher negative values occur after the initial pouring of the concrete face and slowly reduce as time goes on. Modulus of rupture and stress calculations show that the concrete has not been cracked. Figure 4-16 displays the pressure that the concrete undergoes at the three locations where the rebar strain gages are installed; measurements are from the tip of the battered pile. At the bottom of the pile the rebar is in compression, and towards the middle of the pile it moves to tension. The values also show major jumps immediately after the concrete face is pour and after the parapet concrete pour. The positive pressure of the concrete corresponds to the concrete being under pressure which is an expected result.

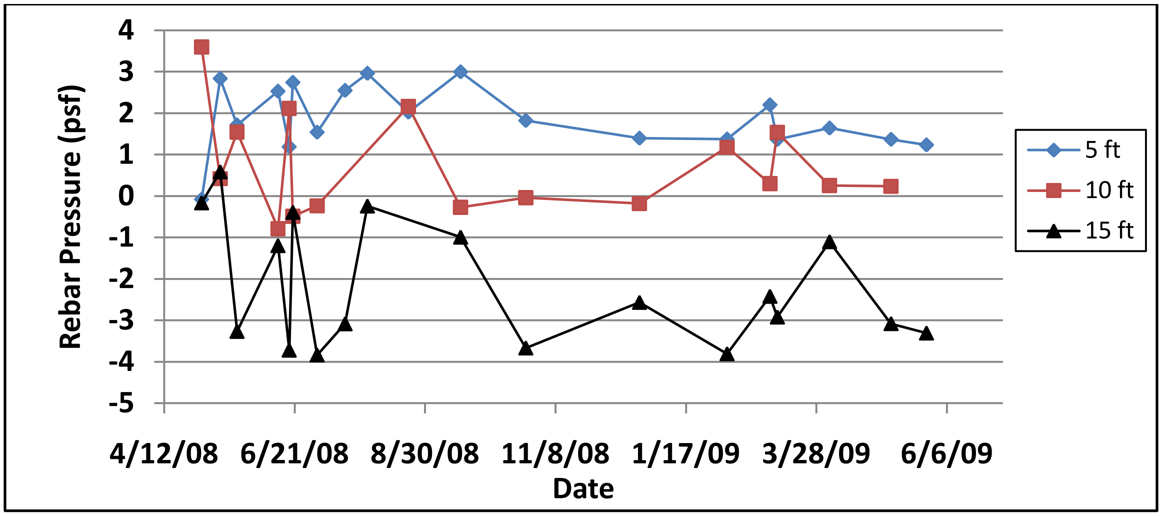


Figure 4-16. Section 1 Rebar Strain Gage Results

Section 2 contained the non-functional gage and the 5 ft location could not be analyzed. The location of the rebar strain gages differed from Section 1 because the concrete form is in the middle of Section 2, see Figure 2-4 for the installation locations. Another major difference in the raw data of the strain readings are the majority of tension, or positive, measurements over time. Where high tension readings are recorded, analysis calculates high stress levels on the inside rebar strain gage, which is almost 4 inches from the inside face of the battered pile, and negative pressure per square foot of the concrete. In Figure 4-17 pressure over time is shown for Section 2. The constant negative pressure indicate that the rebar strain gages continue to measure positive strain in the concrete. This positive measurement suggests that the concrete is experiencing slight changes in expansion. The expansion could have been due to the concrete creating

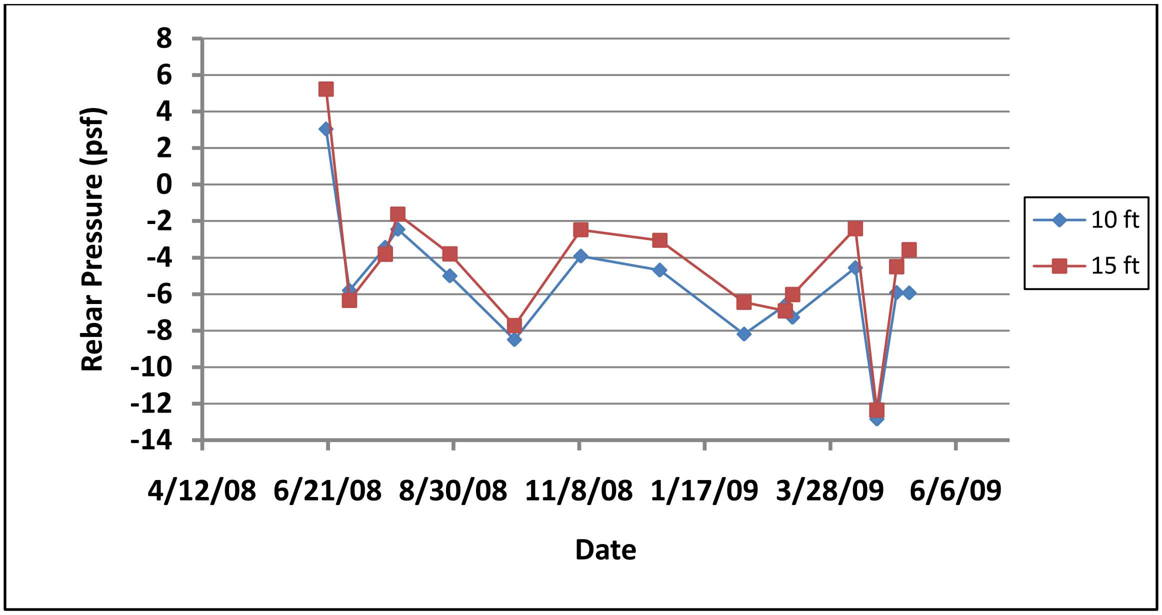


Figure 4-17. Section 2 Rebar Strain Gage Results

too many voids and moisture being absorbed and trapped in the concrete during cold temperatures.

4.5 Lateral Movement

Inclinometer instruments are used to measure the displacement in the retained soil at three locations behind the wall: Section 1, at the high point, and Section 2. Figure 4-18 and 4-19 show the displacement of the soil behind Section 1 and at the high point of the wall. Unfortunately, a contractor incidentally cut the inclinometer casing at Section 2 approximately 2 feet. This caused errors when comparing the new data to the initial data. Therefore, a new initial date was made in April 2009 and additional data must be retrieved to further analyze the results.

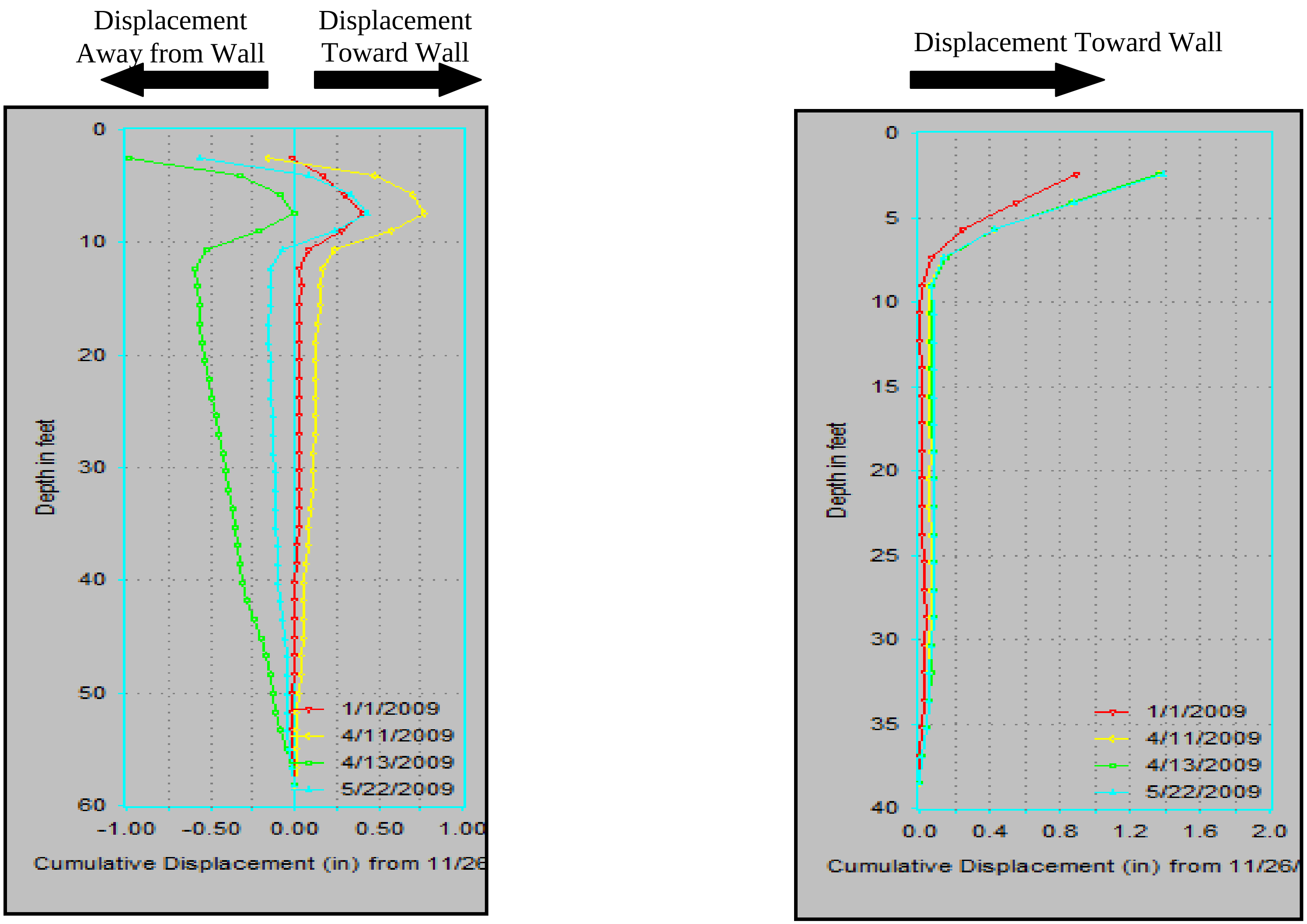


Figure 4-18. Inclinometer Results Behind Section 1 and at High Point (Durham Geo Slope Indicator 2007)

The two remaining inclinometer locations results show a minor displacement change over a six month period. The soil is moving away from the wall when a negative result is shown and toward the wall when a positive result is shown. The results for the top ten feet of the wall can be neglected. The inclinometer casing above and just below the ground has large movements due to the weight from pulling the inclinometer instrument in soil that is not as firm.

The soil behind Section 1 shows a displacement ranging from -0.6in to +0.1in. The April 13 reading shows a larger displacement away from the wall. This variation could be due to soil pressure against the casing. The next reading on May 22 begins to spring back after the soil has settled. The inclinometer results of the soil at the high point of the wall shows smaller changes in displacement over time. However, the lateral movement of the soil is measured in inches and the changes that have been observed over the research period are minimal.

Chapter 5: Conclusions and Future Recommendations

5.1 Temperature Correlations

In order to determine the entire structural behavior on each test section, results from different analysis were combined to examine correlation. The main objective is to observe any links between steel pile behavior, anchor loading, and soil pressure over time. Relationships between earth pressures and pile behaviors are difficult to assume due to the often irregular results of preliminary analysis. However, at the center pressure gages at Section 1 some association can be seen at temperature changes. The two higher gages had a slightly higher pressure after the concrete pour and a lower pressure during the colder months. The east and west battered piles reacted to the soil pressure by having less force during the colder months, despite the east pile being in tension throughout the research period.

Anchor loads from the Section 1 test section showed a typical high load value after the concrete pours and a decrease in loads throughout the winter 2008 season. Loads did not begin to increase until March 2009. The Vertical piles had higher load results for both piles 10-15 ft below the whaler, and lower loads at the top and middle of the vertical piles. The moment results were larger where loads were also increased, as expected. The reaction of the anchor load force on the west pile shows less force overtime at a location directly beneath the load cells which correlates to the load cell results. Forces on the vertical piles located above the anchors show more force overtime which could be the result of the concrete parapet weight. Vertical pile results from the east pile showed small variations in readings.

5.2 Conclusions

Several conclusions can be made about the preliminary behavior of the pile framed tie back retaining wall based on earth pressure results, soil displacement, anchor loading, and pile loading. Earth pressure results suggest that the soil has not made complete contact with the retaining wall and is withstanding on its own because of the low and insignificant measurements of pressure. The inclinometer readings support this assumption and show displacements away from the wall with a maximum of only a half of an inch. Until the wall begins to fully retain the soil, earth pressure analyses can not be concluded.

Anchor load results confirm assumptions that the changes in the anchor loading resulted from temperature variations. The vertical and battered piles transfer the majority of the loads that the retaining wall supports. The data also confirms the relationship between bending and loading illustrating that more compressive forces yield positive moment values and more tensile forces yield negative moment values.

Significance of temperature was a major factor with all instruments and results. During early analyses of the retaining wall, low forces and pressures were determined, and most of these small values can be credited to temperature change. Over time, the soil will add more loading on the wall causing large forces to develop and the effect of temperature with become negligible.

5.3 Future recommendations

Analyses from this research are based on preliminary results of the Smart Fix I-40 pile framed tie back retaining wall. Therefore, an ultimate design recommendation, such as steel pile size, cannot be determined immediately. For example, earlier research suggested that maximum earth pressures would occur closer to final grade of the retaining wall. (Branch) Current results do not reflect this model and suggest lower pressures near final grade. However, due to most areas of the soil not contacting the wall, more time is needed to check this theory. More model analysis should be performed to predict behavior at ultimate capacities based on soil pressures at different soil conditions that were analyzed in ADINA. Knowing the results at failure is needed to ensure that the instrumentation is accurately recording the behavior of the wall. Consistent monitoring of the wall over several years will determine when measurements increase and become steady to the pressures of the retained soil.

Despite the preliminary results, recommendations can be made with future instrumentation monitoring and analysis. The effects of seasonal change should be documented throughout the years to determine how large a role temperature plays on the forces and pressures the wall undergoes. Preliminary results show that temperature had a large affect on pressure cell data and may have caused small cracking on the inside of the concrete face. Therefore, increased monitoring could determine the validity of the instrument readings.

Another recommendation for future research study for the pile framed tie back retaining wall are greater protection measures used for instrumentation. The strain gages experienced more instrumentation loss of 12 gages which is about 7% of the total gages. The loss in gages is low, but often occurred within the same set which made analysis more difficult. Cable connections to the strain gages were also affected. The temperature wire often showed inaccurate or no readings. Better protection of the gages before the piles are driven is crucial to ensure a lower percentage of instrumentation loss and accuracy of data.

List of References

Branch, Eli. (2007). Numerical Analysis of Piling Framed Tie-Down Concrete RetainingWall. Master's Thesis, University of Tennessee.

DMMWin Software (2007). Durham Geo Slope Indicator (CD-ROM), Stone Mountain, GA.

Pate and Haddad (2007). Piling Framed Tie Down Concrete Retaining Wall. *Deep Foundations Magazine,* Spring 2007, 45-48.

The Tennessee Department of Transportation (2008) "Smart Fix 40 Project Briefing."

Wilbur Smith Associates, Inc (2007). Report of Geotechnical Exploration for Retaining Wall 7, Knoxville, TN. WSA Project No. 367102

Appendix

Appendix A
Construction Details

A.1 Construction Documentation

10/1/2007
*Pile driving for test Section 2.

10/2/2007
*Pile driving for test Section 1.

10/3/2007
*Strain gage readings of Section 1 and 2 (Gages 1-84; 102-108).

11/9/2007
*Strain gage readings of Section 2 whalers. Anchors loaded with 50 kips.

11/21/2007
*Strain gage readings of Section 2 after excavation of 6 ft and a backfill of 1 ft.
Anchor loads on whalers tensioned to 100 kips.

12/14/2007
Strain gage readings of Section 1 whalers. Anchors loaded with 50 kips.

12/18/2007
Strain gage readings of Section 1 before scheduled excavation.

12/20/2007
First lift of Section 1, excavation of ~ 8ft.
Section 1 strain gage readings. Section 1 and 2 load cell readings.

12/21/2007
First lift of Section 2, excavation of ~ 9.6 ft.
Section 2 strain gage readings, Section 1 and 2 load cell readings.

1/4/2008
Section 1 and 2 load cell readings.

1/7/2008
Second lift of Section 1, excavation of ~ 17 ft.

Section 1 strain gage readings. Section 1 and 2 load cell readings.

1/8/2008
Second lift of Section 2, excavation of ~18 ft.
Section 2 strain gage readings. Section 1 and 2 load cell readings.

1/14/2008
Third lift of Section 1, excavation of ~ 23 ½ ft.
Section 1 strain gage readings. Section 1 and 2 load cell readings.

1/15/2008
Third lift of Section 2, excavation of ~ 27 ft.
Section 2 strain gage readings. Section 1 and 2 load cell readings.

1/23/2008
Fourth lift of Section 1, excavation of ~31 ¼ ft.
It appears that more dirt was added to Section 2, it is no ~23 ¼ ft.
Section 1 strain gage readings. Section 1 and 2 load cell readings.

2/1/2008
It appears that final grad has been reached on Section 1, ~30 ½ ft.
Section 1 strain gage readings. Section 1 and 2 load cell readings.

2/16/2008
It appears that final grade has been reached on Section 2, ~25 ft.
Section 2 strain gage readings. Section 1 and 2 load cell readings.

3/1/2008
Section 1 - ~31 ft.
Section 2 - ~ 24 ft.
Section 1 and 2 strain gage and load cell readings.

3/24/2008
No significant grade change.
Section 1 and 2 strain gage and load cell readings.

4/21/2008
Delivery of earth pressure cells and rebar strain gages.

4/22/2008
Earth pressure cell reading at Berry Hall under no load.

4/23/2008
Installation of Section 1 earth pressure cells.
Section 1 pressure cells reading with no load.

4/24/2008
Rebar strain gage reading at Berry Hall under no load.

4/28/2008
Section 1 wires were bundled together to prepare for concrete pour.
Section 1 strain gage, earth pressure cell, and load cell readings.
Section 2 strain gage and load cell readings.

4/30/2008
Installation of Section 1 rebar strain gages.
Section 1 rebar strain gage readings with no load.

5/1/2008
Concrete face pour over Section 1.

5/2/2008
Section 1 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

5/10/2008
Section 1 and 2 load cell readings.

5/12/2008
Section 1 strain gage, earth pressure cell, and rebar strain gage readings.
Section 1 and 2 load cell readings.

5/21/2008
Section 1 earth pressure cell and rebar strain gage readings.
Section 1 and 2 load cell readings.

5/22/2008
Section 1 and 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

6/2/2008
Section 2 load cells were foamed to prepare for concrete pour.
Installation of Section 2 earth pressure cells.
Section 2 earth pressure cell and rebar strain gage readings.

6/3/2008
Installation of Section 2 rebar strain gages – only 3 rebar strain gages are installed over the west pile.

6/5/2008
Extended Section 1 cables.

6/6/2008
Concrete face pour over Section 2.
Joint is in the middle of Section 2, therefore only west section has concrete.

6/9/2008
Section 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

6/12/2008
Section 1 and 2 earth pressure cell, rebar strain gage, and load cell readings.

6/17/2008
Installation of remaining 9 rebar strain gages on Section 2.

6/18/2008
Section 1 and 2 earth pressure cell, rebar strain gage, and load cell readings.

6/19/2008
Concrete face pour over the rest of Section 2.
Blalock concrete testing: slump and pressure tests.
Six cylinders made and brought back to Estabrook Hall.

6/20/2008
Section 1 and 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

6/30/2008
Repaired strain gage cords (extended).

7/1/2008
Received rented Readout Box GK-403 (06-13815).

7/2/08-7/3/08
Section 1 and 2 earth pressure cell, rebar strain gage, and load cell readings.
Readings with rented Readout Box GK-403.
Fuse broke and readings were continued on 7/3/08.

7/8/2008
Cut 1 CSG c10 wire and used the wire to extend EP1 e 12.

7/14/2008
Cut EP2 c 4 and EP2 c 8 wires and used the wire to extend 2 CSG e 20 and 2 CSG c 10.

7/17/2008
Concrete cap pour over Section 1.

7/18/2008
Section 1 strain gage, earth pressure cell, rebar strain gage, and load cell readings.
May have lost a rebar strain gage in the cap pour??

7/22/2008
Broke 2 molds from 6/19/08 cylinders.

7/23/08-7/24/08
Section 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

7/30/2008
Some Section 2 readings, but backfilling of Section 1 in progress and had to stop readings for safety.
Broke 4 molds from 6/19/08 cylinders.

7/31/2008
Section 1 and 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

8/20/2008
Section 1 strain gage, earth pressure cell, rebar strain gage, and load cell readings.
Drilling holes for sound walls in progress.
Check 1 CSG w 20! Mislabeled as EP1 e 12 in readout box.

8/28/2008
Section 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

9/18/2008
Section 1 strain gage, earth pressure cell, rebar strain gage, and load cell readings.
Sound wall is being installed and Section 2 is mostly backfilled.

10/3/2008
Section 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

10/23/2008
Inclinometer casing installed.
Section 1 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

11/9/2008
Section 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

12/23/2008
Section 1 and 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.
1/12/2008
Inclinometer readings – initial.

2/8/2009
Section 1 and 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

3/3/2009
Section 1 and 2 earth pressure cell readings - cold readings.

3/7/2009
Section 1 and 2 earth pressure cell readings – warm readings.
Section 1 and 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.

4/4/2009
Section 1 strain gage, earth pressure cell, rebar strain gage, and load cell readings.
Last readings before Data Acquisition System is installed.
Labeled wires to prepare for Data Acquisition System.

4/5/2009
Data Acquisition System installed for Section 1.

4/11/2009
Section 2 strain gage, earth pressure cell, rebar strain gage, and load cell readings.
Inclinometer readings.
3 inclinometer has been cut ~ 2 feet, but is still readable.
Section 1 Data Acquisition System installed.

4/13/2009
Inclinometer reading.

4/24/2009
Section 2 Data Acquisition System installed.

5/22/2009
Inclinometer reading.
*Notes were taken by Nathan Felosi

A.2 Table of Readings

Table A-1 Section 1 Reading Schedule		
Date	Project Day	Activity
5/1/2008	1	Concrete Face Pour
5/2/2008	2	All instrument readings
5/10/2008	10	Load cell only readings
5/12/2008	12	All instrument readings
5/21/2008	21	Load cell only readings
6/2/2008	33	Load cell only readings
6/12/2008	43	Load cell only readings
6/18/2008	49	Load cell only readings
6/20/2008	51	All instrument readings
7/3/2008	64	Rebar/Pressure only readings
7/17/2008	78	Concrete Parapet Pour
7/18/2008	79	All instrument readings-no load cell
7/31/2008	92	All instrument readings-no load cell
8/20/2008	112	Load cell only readings
8/21/2008	113	All instrument readings
8/28/2008	120	Load cell only readings
9/18/2008	141	All instrument readings
10/3/2008	156	Load cell only readings
10/23/2008	176	Inclinometer installation All instrument readings
11/9/2008	193	Load cell only readings
11/26/2008	210	Initial Inclinometer readings
12/23/2008	237	All instrument readings
2/8/2009	284	All instrument readings
3/3/2009	307	Rebar/Pressure only readings
3/7/2009	311	All instrument readings
4/4/2009	339	All instrument readings
4/11/2009	346	Data Acquisition Installed
5/7/2009	372	Data Acquisition readings
5/22/2009	387	Data Acquisition readings
5/26/2009	391	Data Acquisition readings

Table A-2 Section 2 Reading Schedule		
Date	Project Day	Activity
6/6/2008	1	West Pile Concrete Face Pour
6-9-2008	4	All instrument readings
6/12/2008	7	Rebar/Pressure/Load only readings
6/17/2008	12	East Pile Concrete Face Pour
6/18/2008	13	Rebar/Pressure/Load only readings
6/20/2008	15	All instrument readings
7/3/2008	28	Rebar/Pressure only readings
7/22/2008	47	Concrete Parapet Pour
7/23/2008	48	All instrument readings
7/30/2008	55	All instrument readings
7/31/2008	56	All instrument readings
8/28/2008	84	All instrument readings
10/3/2008	120	All instrument readings
10/23/2008	140	Inclinometer installation
11/9/2008	157	All instrument readings
11/26/2008	174	Incl in. reading
12/23/2008	201	All instrument readings
2/8/2009	248	All instrument readings
3/3/2009	271	Rebar/Pressure only readings
3/7/2009	275	All instrument readings
4/11/2009	310	All instrument readings
4/23/2009	322	Rebar/Pressure/Load only readings
4/24/2009	323	Data aq installation
5/4/2009	333	Rebar/Pressure/Load only readings
5/11/2009	340	Rebar/Pressure/Load only readings

Appendix B
Strain Gage

B.1 Vertical and Battered Pile Layouts

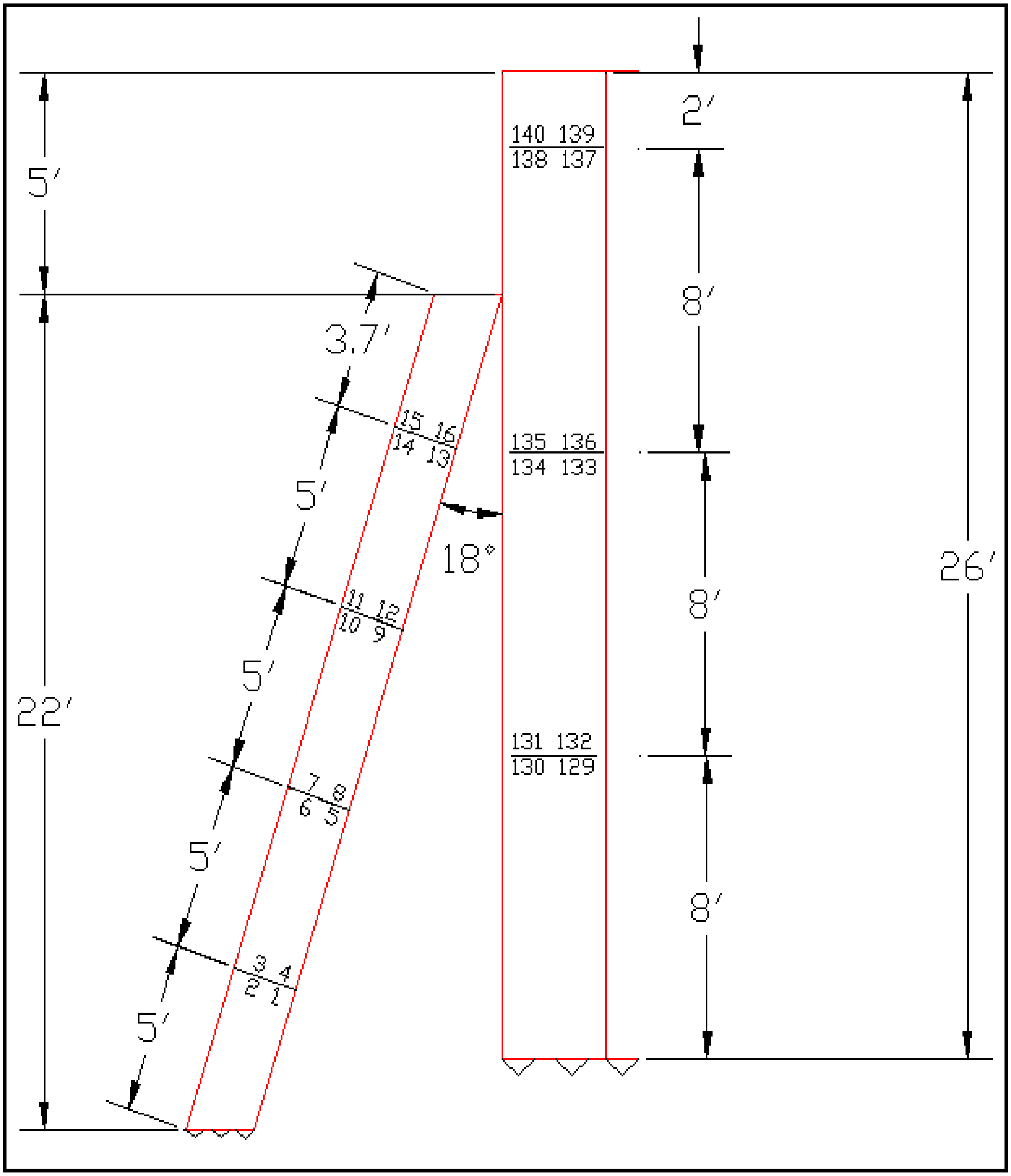


Figure B-1. Strain Gage Layout of Section 1 W

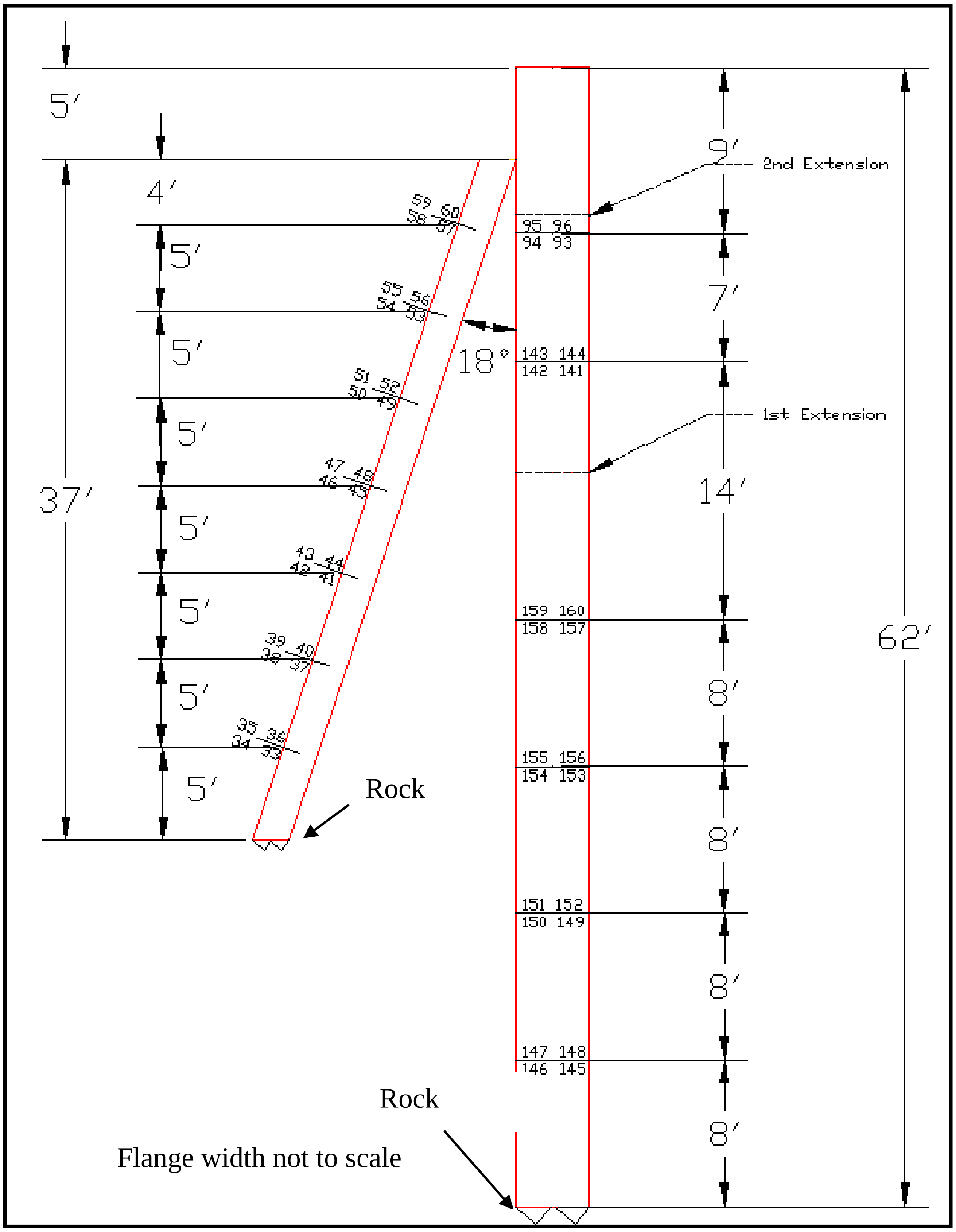


Figure B-2. Strain Gage Layout of Section 1 E

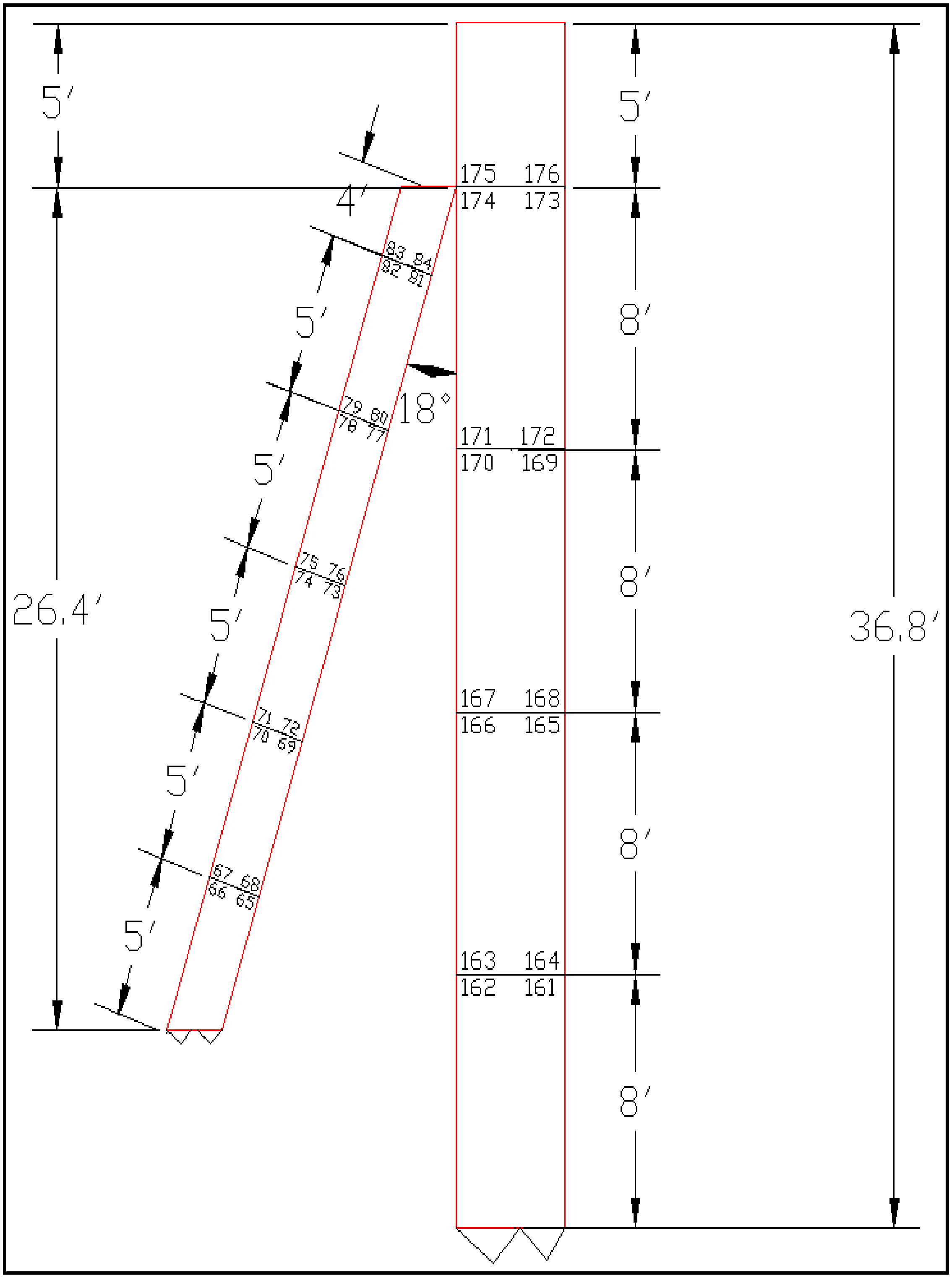


Figure B-3. Strain Gage Layout of Section 2 W

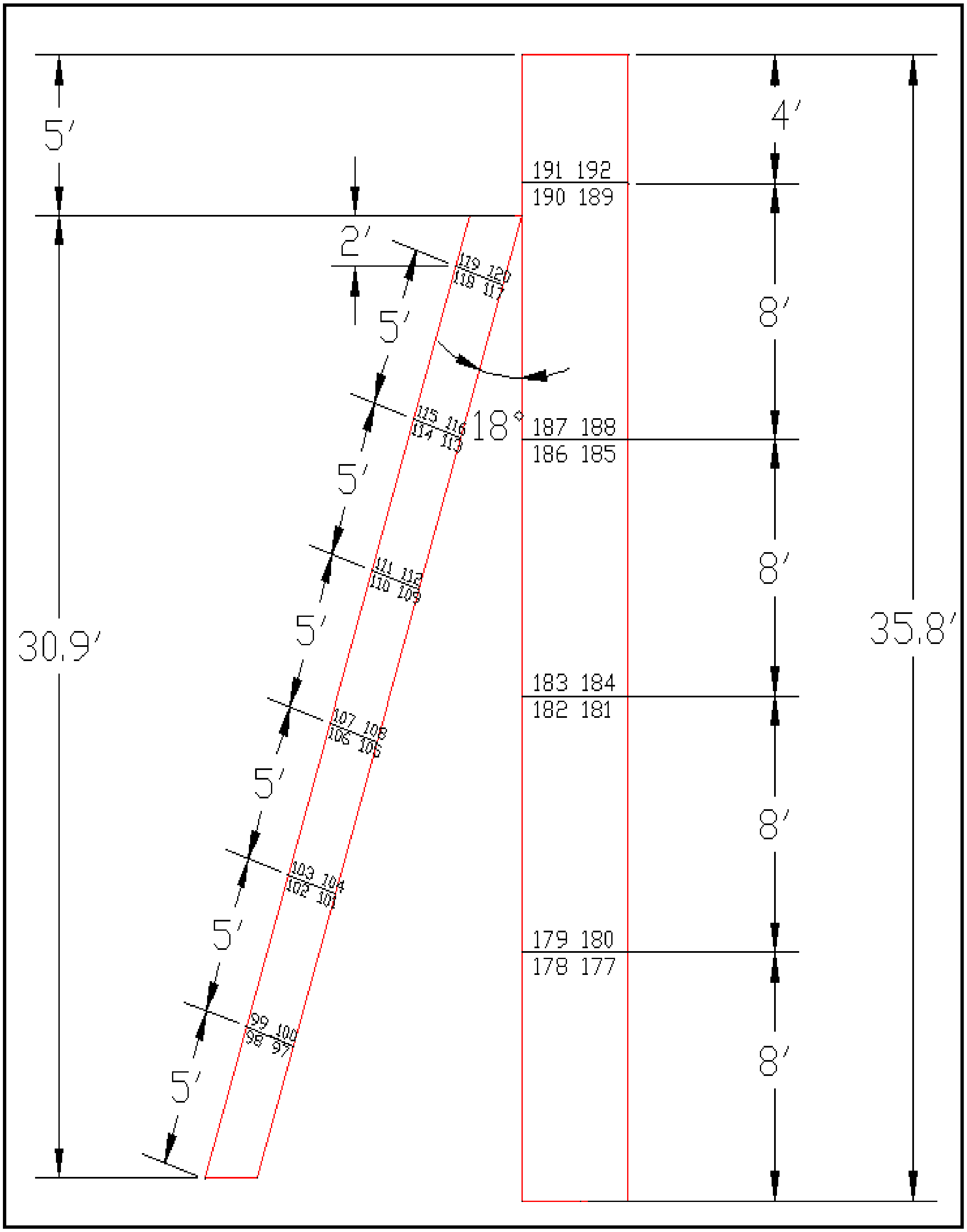


Figure B-4. Strain Gage Layout of Section 2 E

B. 2 Section 2 Vertical Pile Graphs

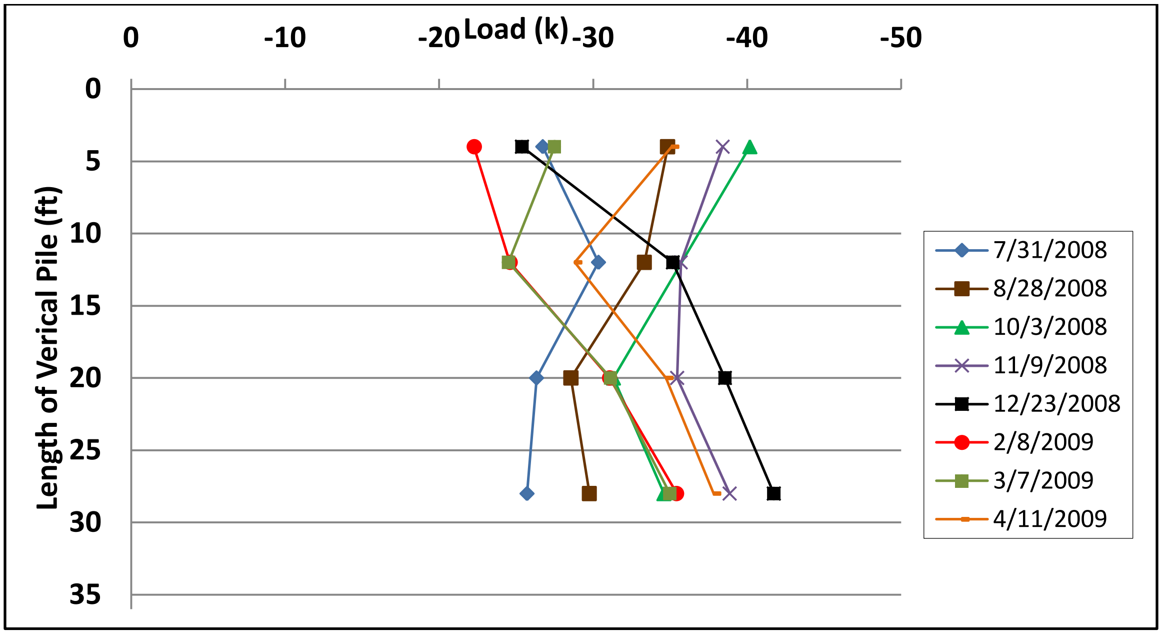
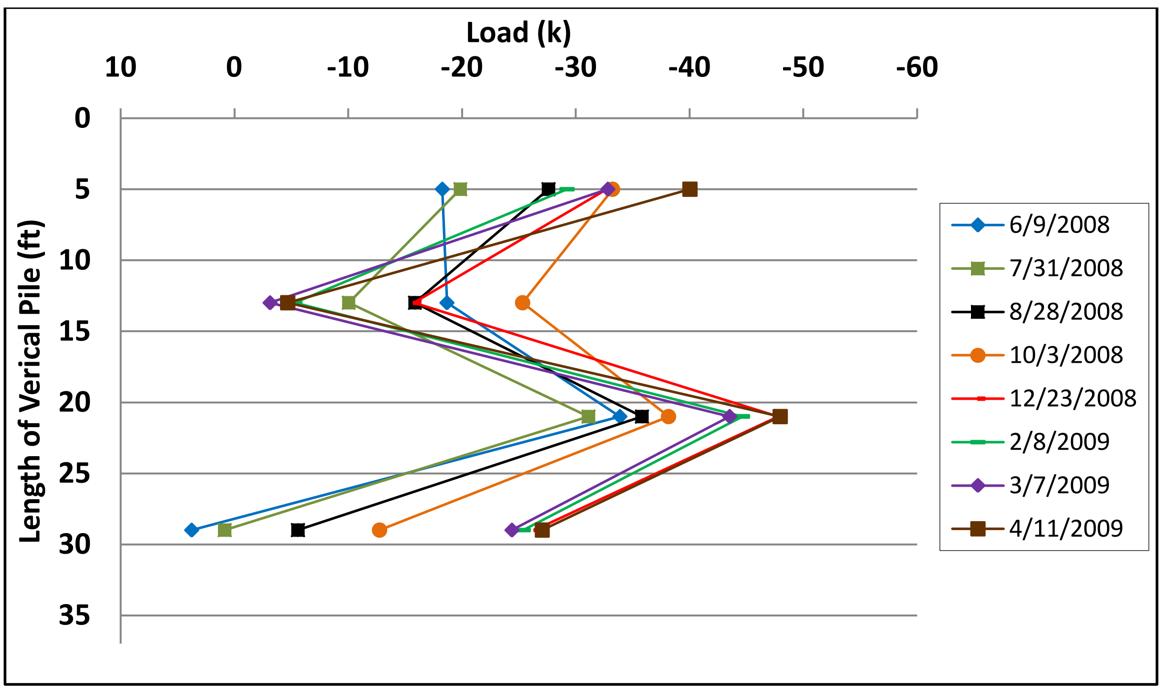
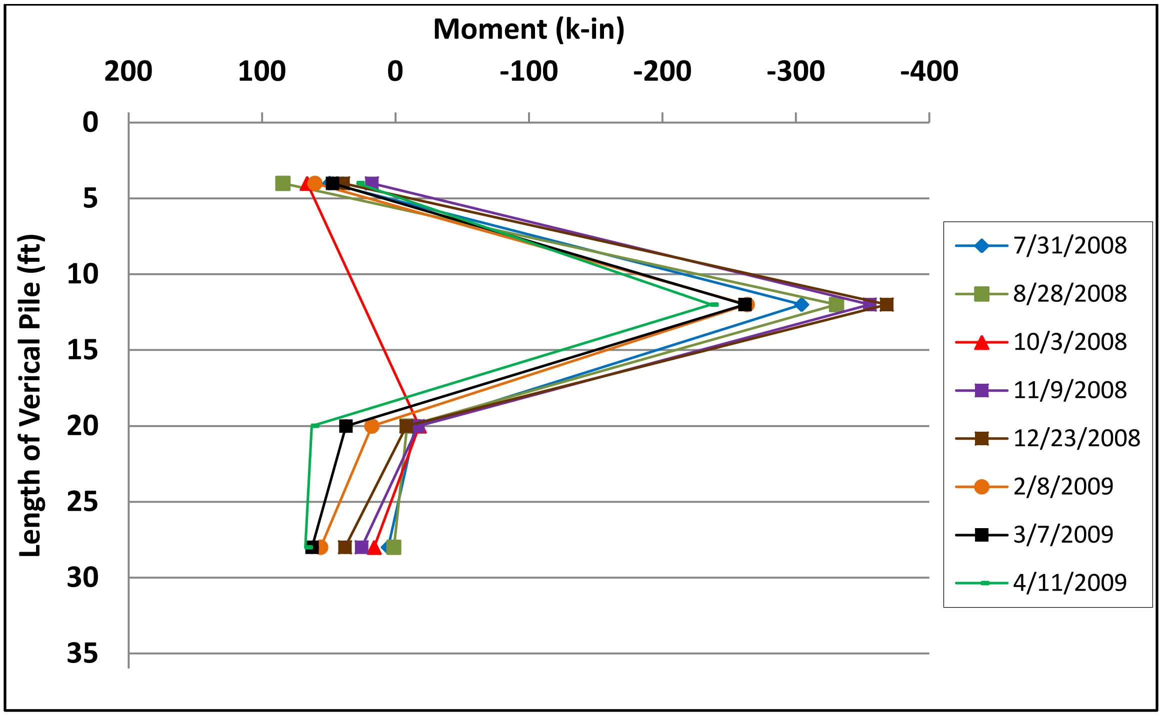


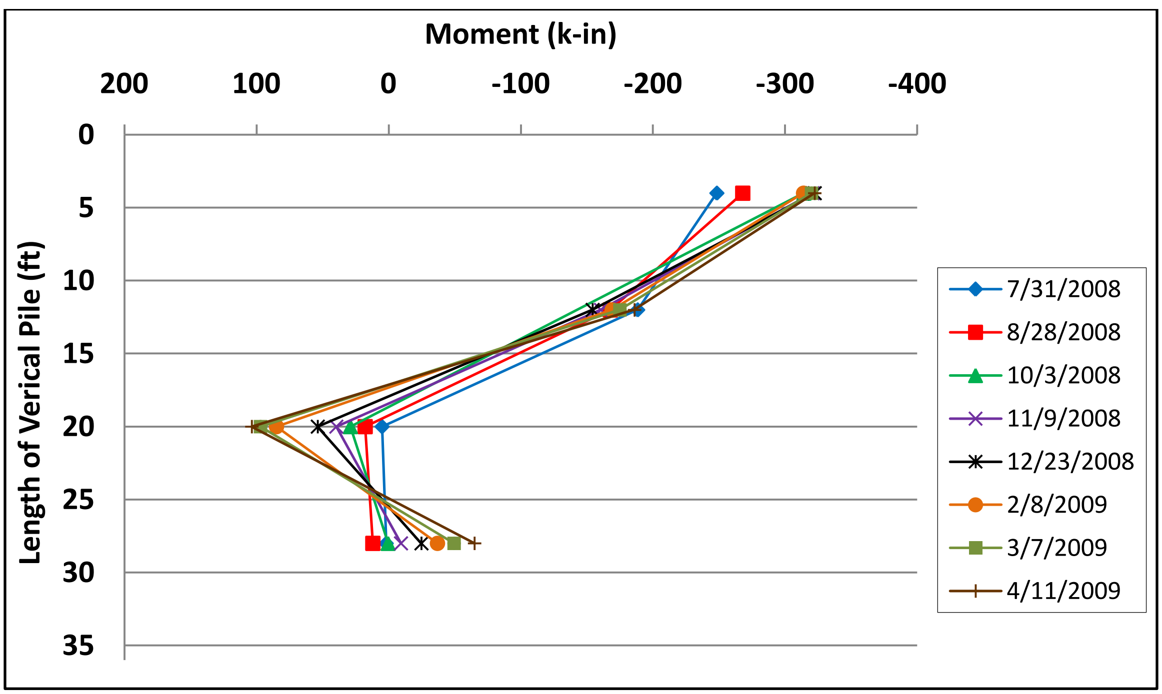
Figure B-5. Section 2E Vertical Pile Load Results



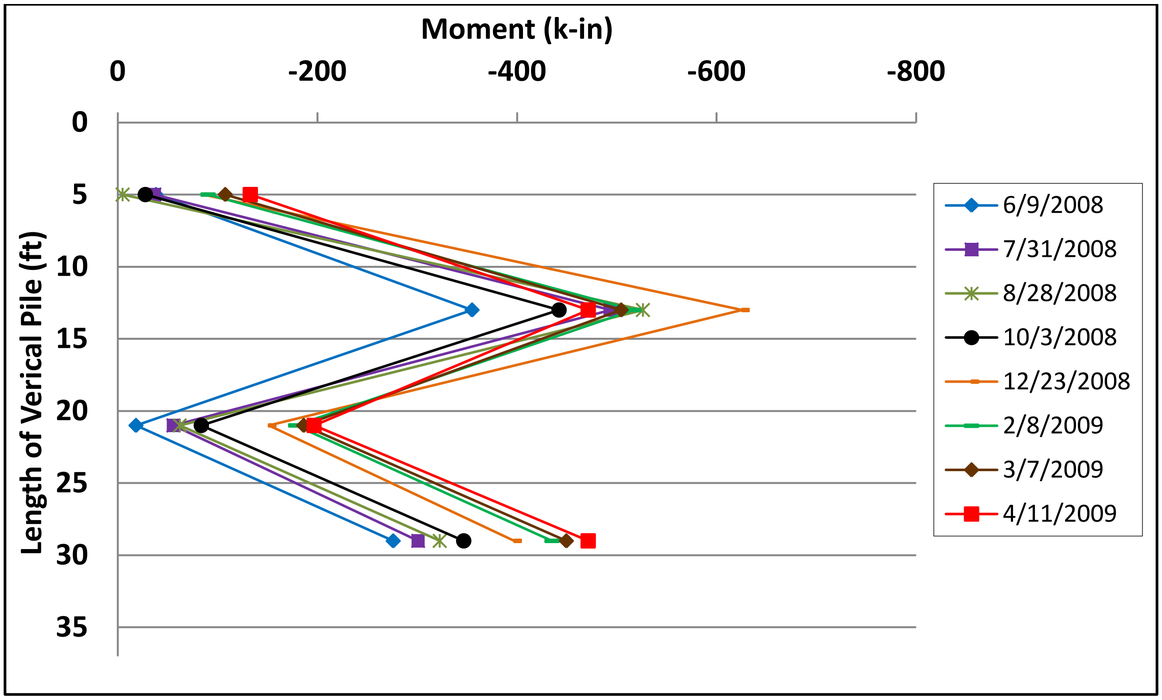
B-6. Section 2W Vertical Pile Load Results



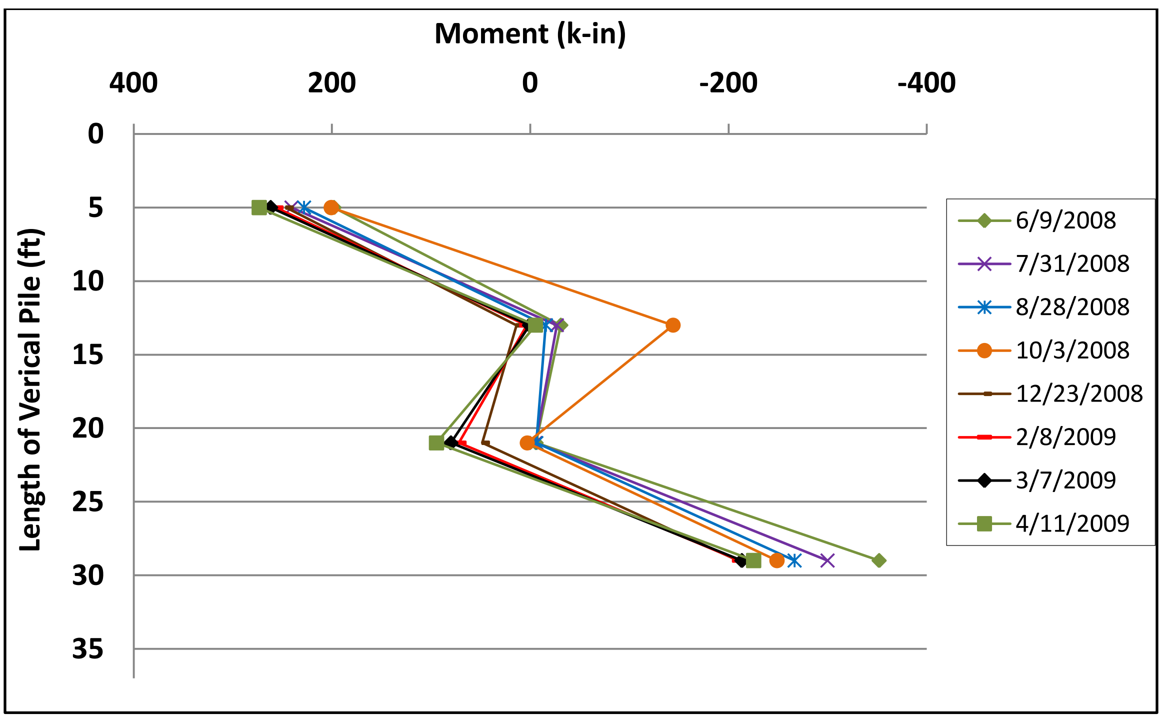
B-7. Section 2E-Vertical Pile Moment Results (strong-axis)



B-8. Section 2E Vertical Pile Moment Results (weak axis)

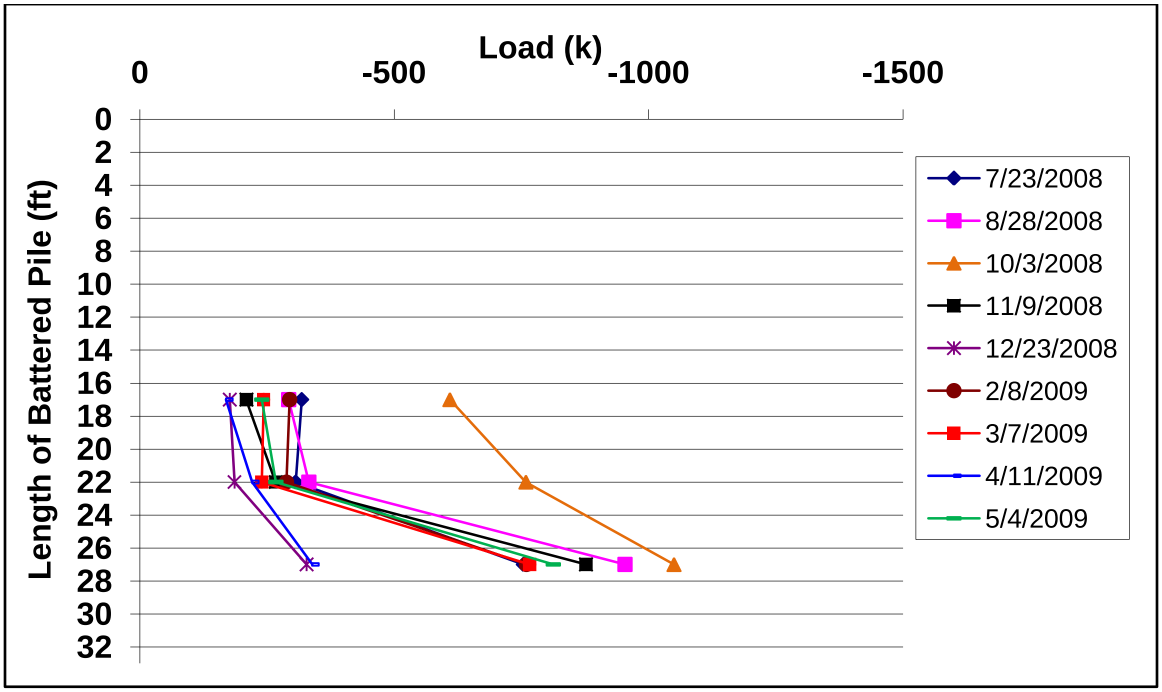


B-9. Section 2W Vertical Pile Moment Results (strong axis)

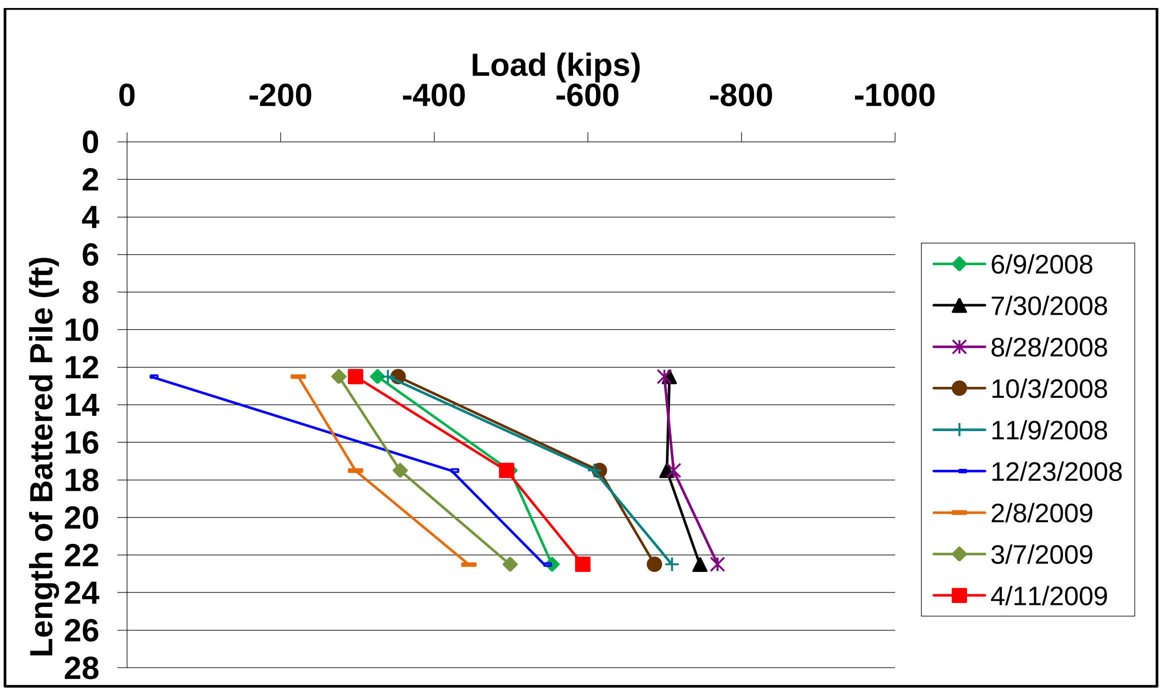


B-10. Section 2W Vertical Pile Moment Results (weak axis)

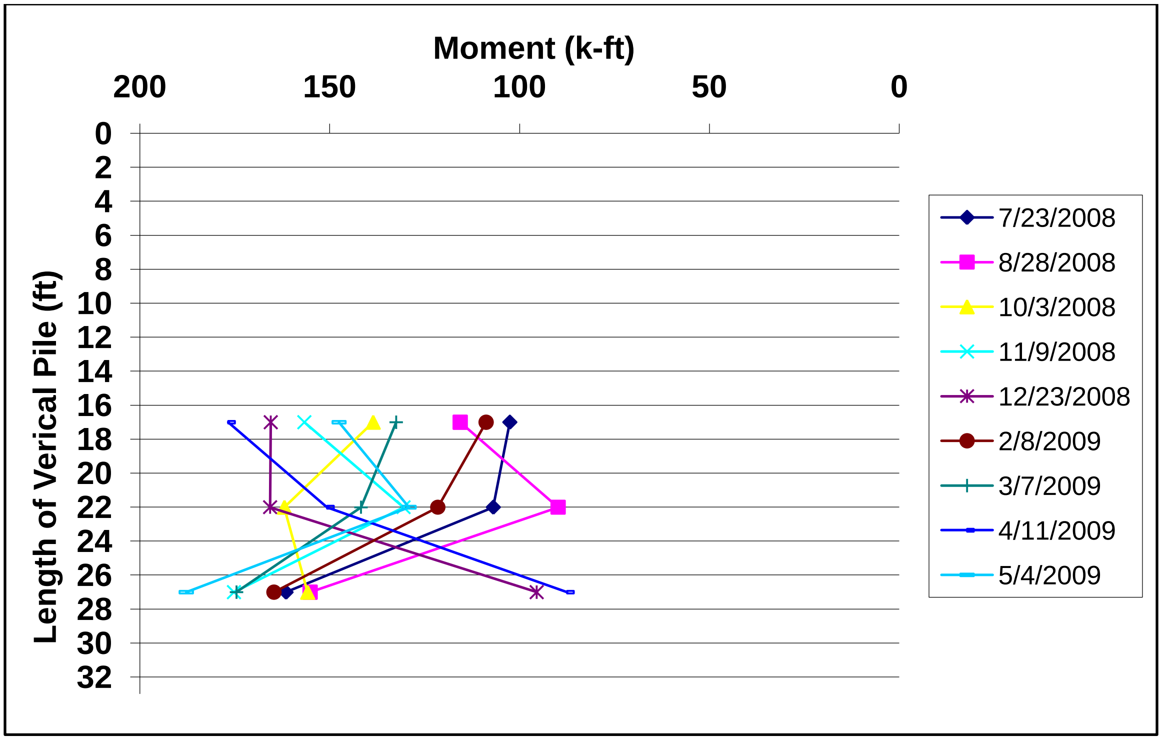
B. 3 Section 2 Battered Pile Graphs



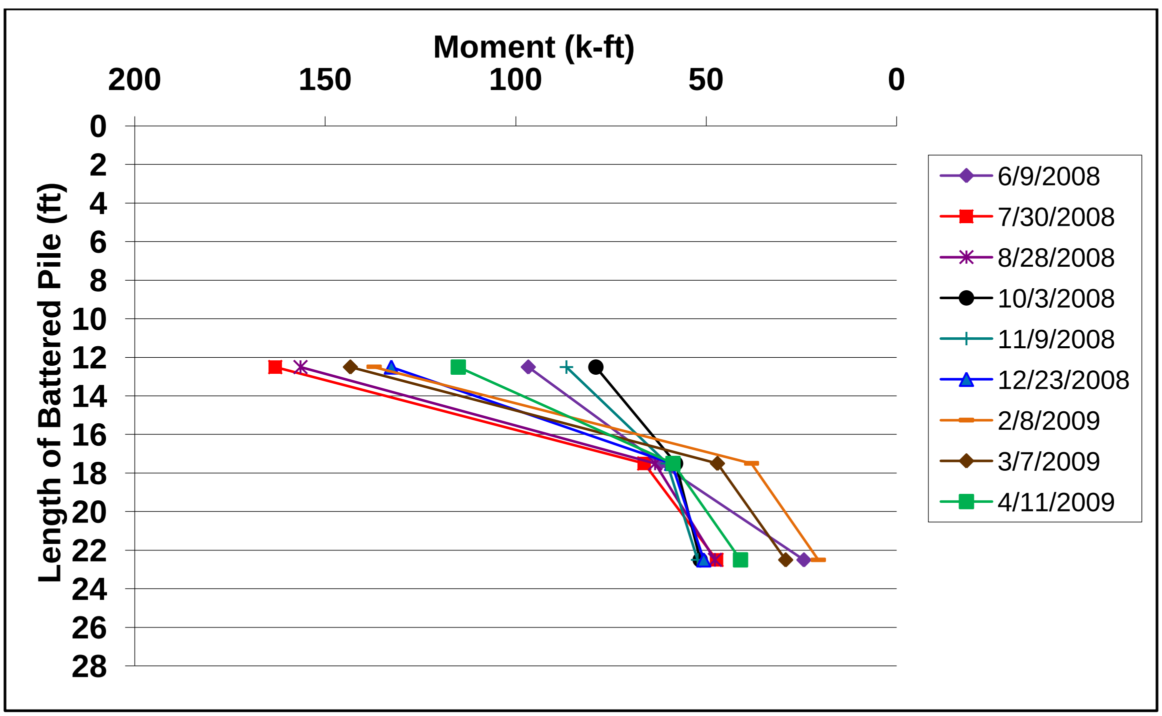
B-11. Section 2E Battered Pile Load Results



B-12. Section 2W Battered Pile Load Results



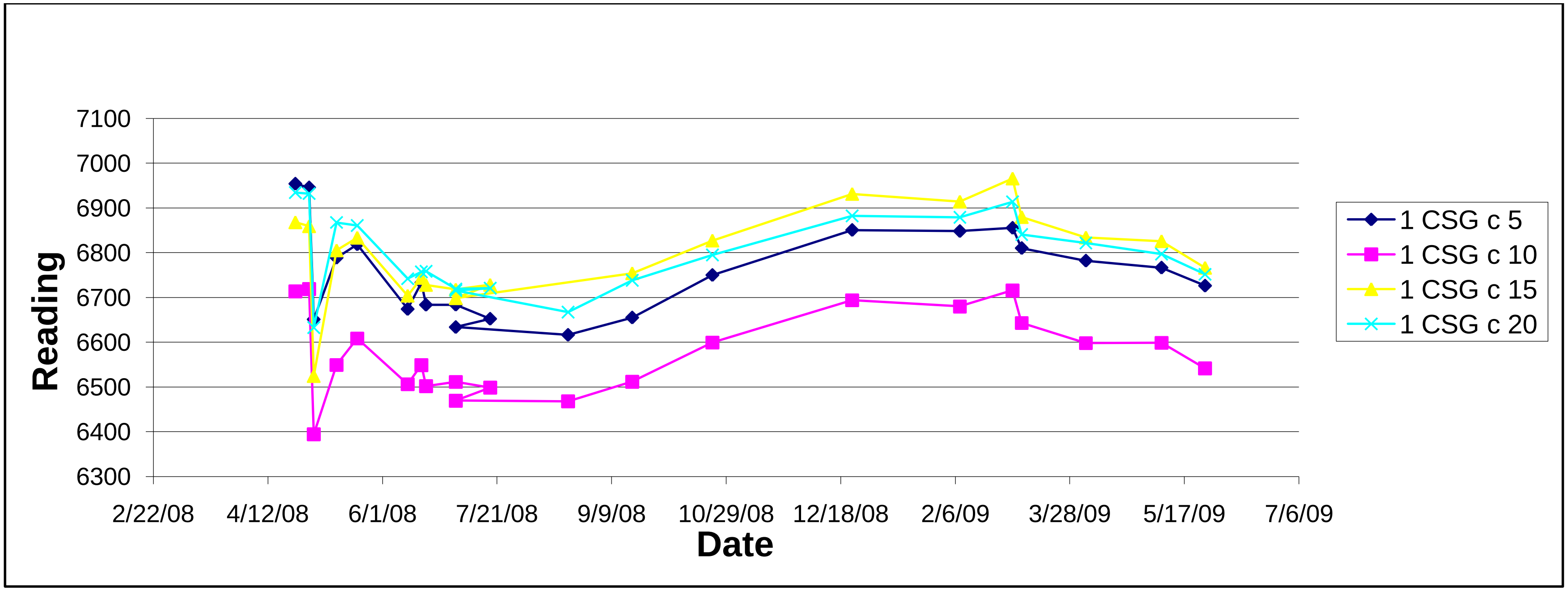
B-13. Section 2E Battered Pile Moment Results



B-14. Section 2W Battered Pile Moment Results

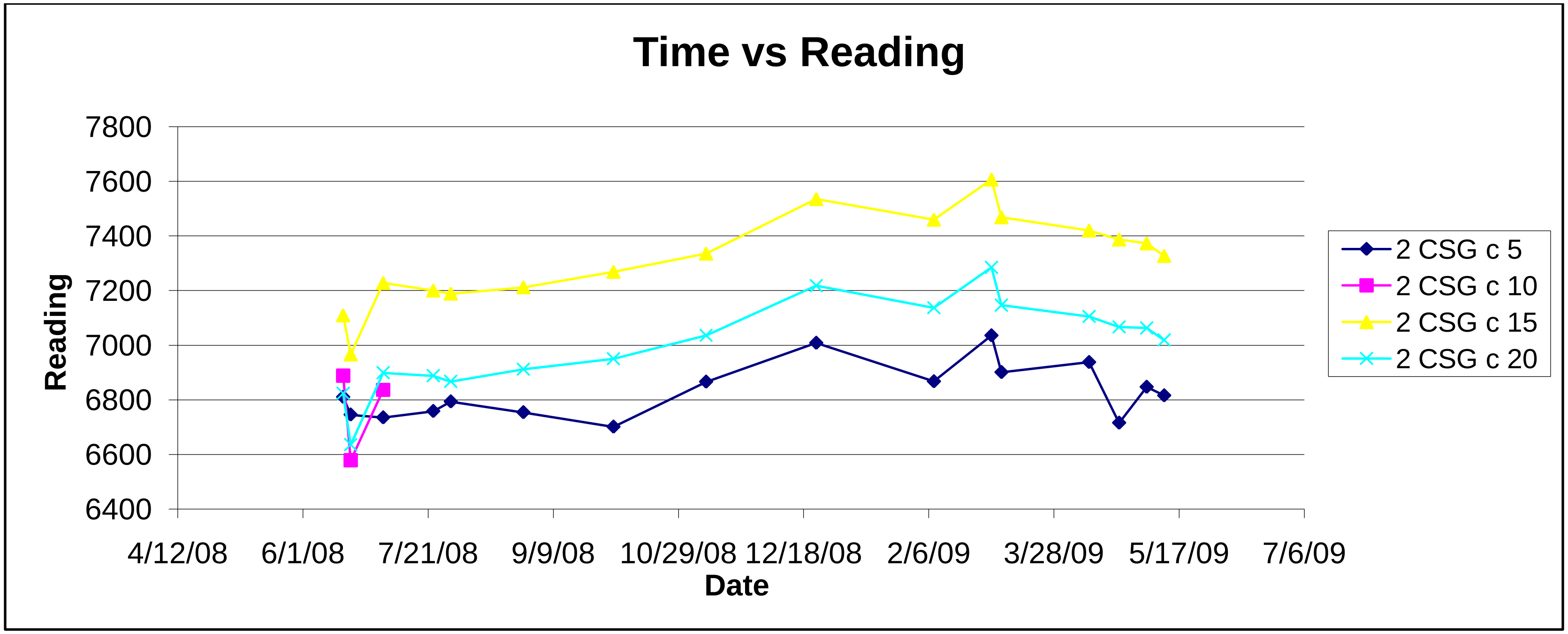
Appendix C
Rebar Strain Gage

C. 1 Section 1 Rebar Strain Gage



C-1. Section 1 Time vs. Reading for Center Gages

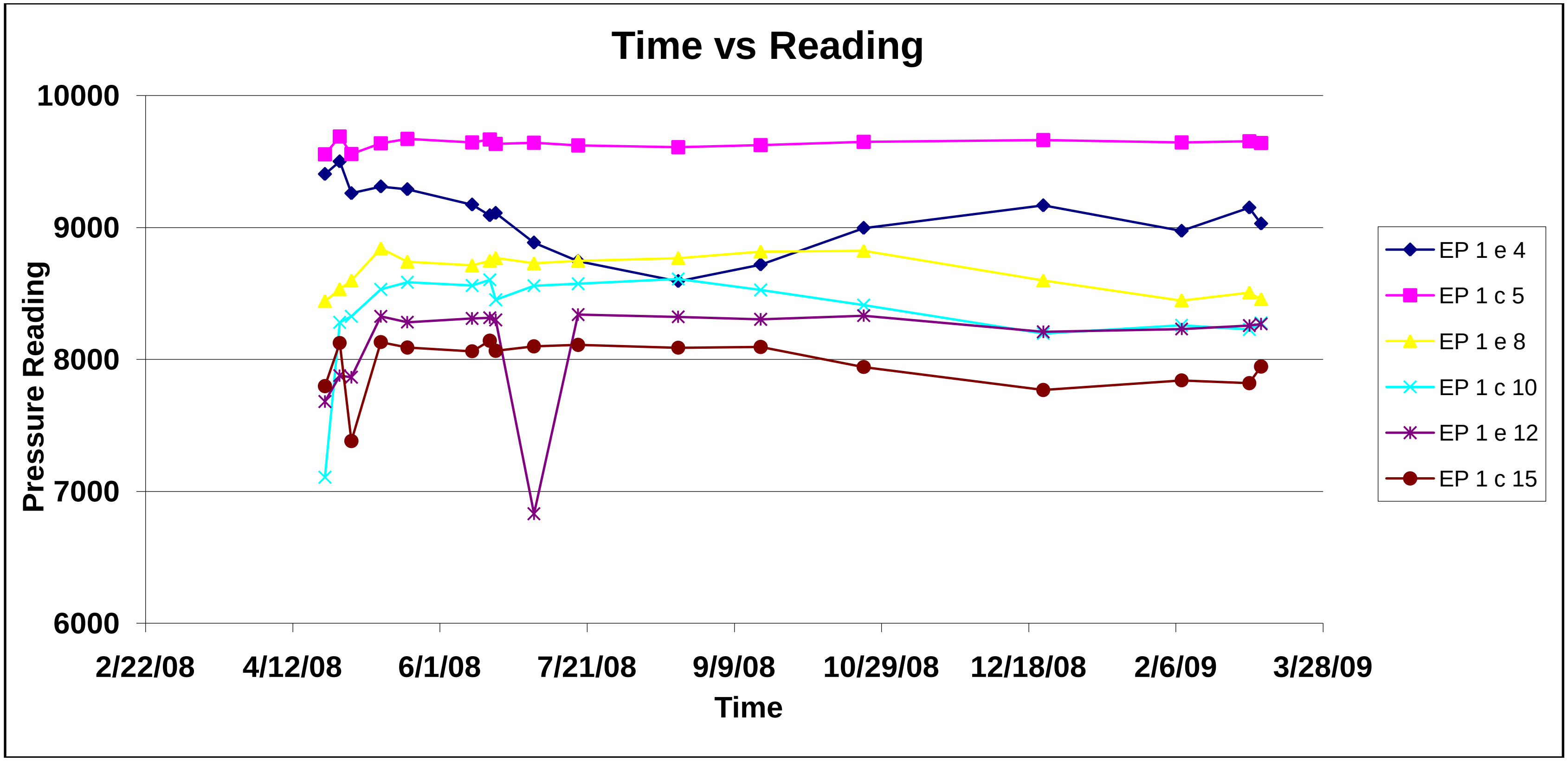
C.2 Section 2 Rebar Strain Gage



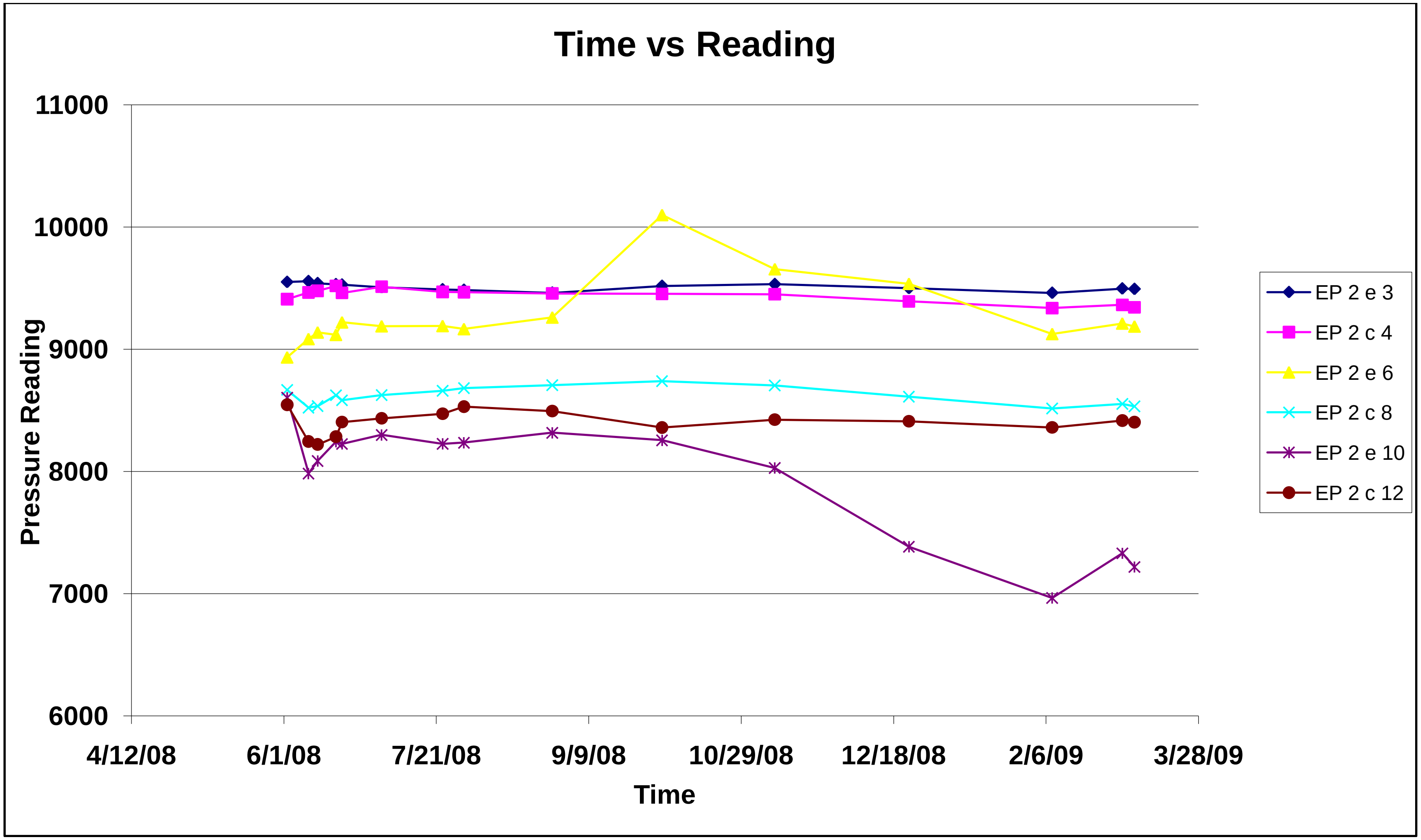
C-2. Section 2 Time vs. Reading for Center Gages

Appendix D
Data Acquisition System

D.1 Section 1 Earth Pressure cell



D.2 Section 2 Earth Pressure cell



Appendix E
Data Acquisition System

E.1 Section 1 and 2 Data Acquisition Wiring Guide

Table E-1. Section 1 Data Acquisition Wiring

Multiplexer #	Analog Inputs
1	1 thru 6: Pressure Cells
	7 thru 16: Rebar Strain Gages
2	1 thru 2: Rebar Strain Gages
	3 thru 8: Load Cells
	9 thru 16: Strain Gages
3	1 thru 16: Strain Gages
4	1 thru 16: Strain Gages
5	1 thru 16: Strain Gages
6	1 thru 16: Strain Gages
7	1 thru 16: Strain Gages
8	1 thru 4: Strain Gages

Table E-2. Section 2 Data Acquisition Wiring

Multiplexer #	Analog Inputs
9	1 thru 6: Pressure Cells
	7 thru 16: Rebar Strain Gages
10	1 thru 2: Rebar Strain Gages
	3 thru 8: Load Cells
	9 thru 16: Strain Gages
11	1 thru 16: Strain Gages
12	1 thru 16: Strain Gages
13	1 thru 16: Strain Gages
14	1 thru 16: Strain Gages
15	1 thru 16: Strain Gages

Appendix F
Concrete Compressive Strength Tests

Concrete cylinder tests were performed throughout the construction of the concrete face and concrete parapet. Two cylinders were tested for compressive strength by TDOT on July 17, 2009 on station 11+70 to 11+40 (made on June 19, 2008). Concrete is specified in the construction general notes to be class A with a strength of 4,000psi. However, the TDOT concrete cylinder test report lists the design strength to be 3000psi. Compressive strength results of the two cylinders were found to be 2880 psi and 3320 psi, with an average of 3100psi.

Six concrete cylinders were made alongside the two TDOT cylinders on June 19, 2008 to perform compressive strength tests for this research. Tests were performed on July 22, 2008 for two cylinders and July 20, 2008 for the remaining cylinders. All tests were performed by Mieah Turner in the Estabrook Hall Lab.

<u>Cylinder 1</u>
Performed: July 22, 2008
Compressive Strength = 3,129 psi
Peak Stress = 88,460 lb

<u>Cylinder 4</u>
Performed: July 22, 2008
Compressive Strength = 3,029 psi
Peak Stress = 85,650 lb

Cylinder 2
Performed: July 30, 2008
Compressive Strength = 3,219 psi
Peak Stress = 91,020 lb


Cylinder 3
Performed: July 30, 2008
Compressive Strength = 2,971 psi
Peak Stress = 84,020 lb


Cylinder 5
Performed: July 30, 2008
Compressive Strength = 3,288 psi
Peak Stress = 92,970 lb

Cylinder 6
Performed: July 30, 2008
Compressive Strength = 3,266 psi
Peak Stress = 92,340 lb

Vita

Mieah Dee Turner was born on June 9, 1985 in Knoxville, Tennessee. She graduated from Bearden High School with honors in 2003. In May 2008, Mieah received her Bachelor of Science Degree in Civil Engineering from The University of Tennessee. She immediately began her Master of Science Degree in Civil Engineering with a concentration in Structures at the same university and graduated in 2009. She is currently using her education knowledge in her professional career.