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Implementation Study: Continuous, Wireless Data Collection and Monitoring of the Sagamore Parkway Bridge

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NOTICE

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16. Abstract

This report presents, in detail, the development and implementation of a wireless solar powered DAQ system for continuous real-time monitoring of the Sagamore Parkway Bridge using the data collected from strain gauges installed in the bridge pier and its foundation piles. The data analysis showed that there is no significant change in the load-settlement response of the bridge pier 3 years after its construction. The pile cap contribution in carrying the total load carried by the bridge pier is significant (about 20%). The hourly ambient temperature trends match with the incremental bending moments measured on the bridge pier and the piles. The daily temperature cycles also affected the load transferred between the piles within the pile group. The water level fluctuations of the Wabash River impacted the total load carried by the pier, such that a rise in water level resulted in slight drop in the total load carried by the bridge pier due to buoyant forces. The overall results of the bridge monitoring showed that the bridge has performed well since its construction.

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EXECUTIVE SUMMARY

Introduction

The new seven-span concrete Sagamore Parkway Bridge over the Wabash River in Lafayette, IN was constructed in November 2018. The new bridge consists of two end-bents (bent 1 and bent 8) and six interior piers (piers 2 to 7) that are founded on closed-ended and open-ended driven pipe piles, respectively. As part of SPR-4165 (*Verification of Bridge Foundation Design Assumptions and Calculations*), one of the bridge piers (pier 7) and its foundation elements were instrumented with strain gauges to monitor the bridge response to dead and live loads. Considering the valuable data obtained from the instrumentation of the pier and the fact that all the strain gauges installed were fully functional and producing valuable data, there was mutual agreement between the Study Advisory Committee (SAC) members to start an implementation project for the long-term monitoring of the Sagamore Parkway Bridge through wireless data collection. The *Implementation Study: Continuous, Wireless Data Collection and Monitoring of the Sagamore Parkway Bridge* (SPR-4546) aimed at implementing a continuous monitoring protocol for the bridge. A wireless data acquisition system was used to collect the data from the strain gauges and the temperature sensors to initiate the study of the effects of water table fluctuations and temperature variations on the bridge performance.

The report presents in detail the implementation of a wireless DAQ system powered by a solar powered system that consists of solar panels and batteries. The data collected includes the total load and settlement of bridge pier 7 under service, the load carried by the pile cap, the load carried by the individual piles supporting pier 7, the daily ambient temperature, and the water level of the Wabash River.

Findings

The data analysis showed that there is no significant change in the load-settlement response of pier 7 after the construction of the bridge. The pile cap is carrying about 20% of the total load carried by the bridge pier. The trend of the hourly ambient temperature variations matches the trend in the incremental bending moment measured on the bridge pier and the piles. The load transferred to the piles within the pile group was also affected by the daily temperature cycles, as expected. The fluctuations of the Wabash River water level had an impact on the total load carried by the pier. It was observed that a rise in water level above the level of the strain gauges installed in the bridge pier generated uplift forces causing a slight drop in the total load carried by the bridge pier.

Implementation

Several implementation items have been identified from this research project.

1. Long-term continuous wireless monitoring of the foundations of the Sagamore Parkway Bridge for completeness of the data set and for future use in design by INDOT is needed.
2. Instrumentation of all the bridge piers or at least more than one pier of another bridge to understand the load redistribution between bridge piers and their foundations in service and to study the deflection response of the bridge in-service is needed.
3. Employment of a similar instrumentation scheme at other bridge sites to augment the dataset acquired in this project with the goal of improving the design and performance of bridge and foundations in the State of Indiana is needed.
4. Consideration of pile cap capacity in other bridge projects in which an instrumentation scheme similar to the Sagamore Parkway Bridge should be implemented.
5. The contribution of the pile cap, as assessed from the monitoring of the Sagamore Parkway Bridge pier for a period of about 4 years, was measured to be at least 18% of the load transferred by the bridge. In foundation design, the contribution of the pile cap in support of the total load may be considered to achieve an economical design. It must be noted that the contribution of the pile cap reported in this study is only applicable to similar foundation layouts, soil type/profile, and loading conditions. Further research is needed to study the effects of different factors affecting the pile cap capacity, such as soil type and profile below the pile cap, pile cap–soil contact, scouring conditions, layout of the pile group, and size of the pile cap.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Background

The Sagamore Parkway Bridge consists of twin, parallel bridges over the Wabash River in Lafayette, IN (40°27′05.7"N 86°53′39.3"W). The bridge was designed by Parsons Consulting Engineers, and its construction started in November 2016 by Superior Construction. The bridge was completed in a period of about 2 years. The bridge structure included two end-bents (bent 1 and bent 8) and six interior piers (pier 2 to pier 7) that are founded on closed-ended and open-ended driven pipe piles, respectively (Han, Prezzi, et al., 2020). Pier 7 and its 15 open-ended pipe piles were instrumented. The load and settlement of the foundations of the Sagamore Parkway Bridge (eastbound bridge) have been monitored throughout the construction stages and during a live load test performed on March 19, 2019 (Han, Marashi, et al., 2020). Taking advantage of the fact that all strain gauges were fully functional and producing valuable data there was a consensus among the SAC members of SPR-4165 to continue monitoring the bridge performance by collecting the data from the strain gauges and the temperature sensor wirelessly. As part of this project, the research team developed the capability of the Data Acquisition (DAQ) System for continuous, wireless readings from the instrumentation. In addition, a scheme was developed to allow the DAQ to be powered only by the solar system, which consists of the solar panels and the solar-powered batteries. The solar system automatically switches between only solar panel—only battery—solar with battery supported modes based on the needs depending on the weather conditions. The effects of the changes in ambient temperature and water elevation of the Wabash River on the loads measured at the bridge pier and the piles supporting pier 7 of the Sagamore Parkway Bridge are reported herein.

1.2 Project Overview

In this report, we present in detail the development of a DAQ system for continuous wireless data collection and the analysis of the data collected from the strain gauges installed on pier 7 and its 15 piles for a period of 5 months (from 07/21 to 11/21). During this period, the impact of environmental factors, such as the ambient temperature and Wabash River water level, on the loads measured were assessed. The valuable data collected in this project and its detailed analysis help with the understanding of the response of bridge foundations under different climatic conditions and can be used to improve design codes and manuals.

1.3 Report Structure

Section 2 presents an overview of the Sagamore Parkway Bridge, including the soil profile at the bridge site and the layout of the bridge structure. The basic properties of the soil at the site are provided in a table and the details of the bridge structure are covered in this section.

Section 3 details the instrumentation scheme of the bridge pier (pier 7) and its foundation elements employed to measure the pier settlement, the load transfer from the superstructure to the foundation elements, and the load distribution among the 15 piles in the group supporting the bridge pier.

Section 4 presents the methodology used to collect the data from the strain gauges and sensors remotely through a cellular wireless network.

Section 5 presents the data collected wirelessly from the strain gauges and sensors. The measurement results are presented in the following sequence.

1. Load-settlement response of the bridge pier.
2. Load transfer from the bridge pier to the foundation piles.
3. Load bearing capacity of the pile cap.
4. Effect of location of temperature sensor on ambient temperature measurements.
5. Bending moment increments in the bridge pier and foundation piles due to daily ambient temperature cycles.
6. Load increments at the pile heads due to daily ambient temperature cycles.
7. Impact of the Wabash River water level fluctuations on the loads transferred to the bridge pier.

Section 6 summarizes the main contents and findings presented in the report.

2. SITE INFORMATION

The Sagamore Parkway Bridge was constructed in the Wabash Valley in Lafayette, IN. The elevation of the lowest point of the river cross section along the bridge (the flow line) is at 500.94-ft above the sea level, and the average river water level is at 510-ft above sea level. Table 2.1 provides the properties of the soils found at this location. Additional information on the site conditions and site investigation results can be found in (Han, Marashi, et al., 2020).

Figure 2.1 shows the layout of the eastbound, 7-span, concrete Sagamore Parkway Bridge. The foundation for pier 7 of the bridge consists of a 7-ft thick pile cap supported by 15 steel open-ended pipe piles (in a 3 × 5 group layout). The bridge pier and all 15 piles were instrumented with strain gauges. Additional information on the foundations of the bridge can be found in Han, Marashi, et al. (2020).

TABLE 2.1
Soil profile near pier 7 (modified after Han, Ganju, et al., 2019)

Layer No.	Depth (m)	Soil Description	γ_t (kN/m^3)	Gravel Content (%)	D_{50} (mm)	C_U	C_C	R	S	USCS Classification
1	0–5.5	Clayey silt with sand	19.5	0	–	3.0	0.8	–	–	–
2	5.5–8.2	Sand with gravel	20.0	4	0.4	2.6	0.9	0.41	0.82	SP
3	8.2–10.4	Sandy gravel	21.5	49	4.5	34.6	0.7	0.44	0.82	SP
4	10.4–16.8	Sand with gravel	20.0	10	0.9	4.8	0.7	0.50	0.84	SP
5	16.8–22.6	Gravely sand	21.5	43	4.1	16.6	0.6	0.46	0.81	SP
6	22.6–32.6	Gravely sand	21.5	28	1.1	8.3	0.8	0.44	0.82	SP

Note: γ_t = total unit weight, D_{50} = mean particle diameter, C_U = coefficient of uniformity = D_{60}/D_{10}, C_C = coefficient of curvature = $(D_{30})^2/(D_{10} \times D_{60})$, R = roundness = the ratio of the average radius of curvature of the corners of the particle to the radius of the maximum circle that can be inscribed, S = sphericity = the ratio of the diameter of a circle with area equal to the projected area of the particle to the diameter of the circumscribing circle to the particle projected area.

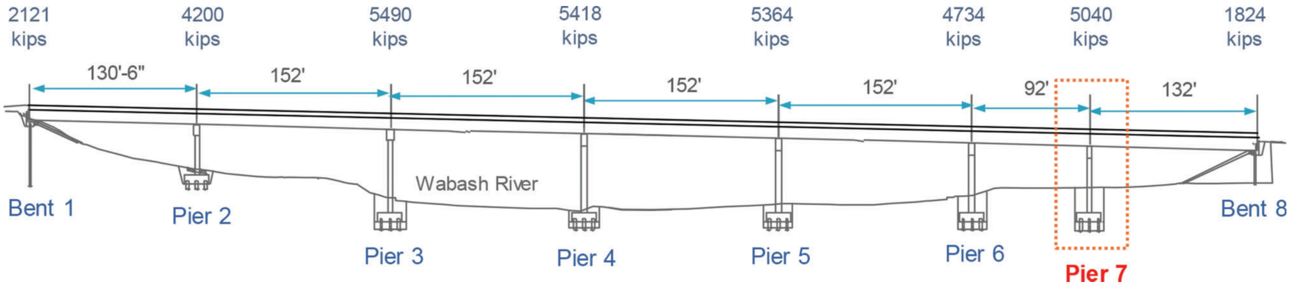


Figure 2.1 Side view of the seven-span Sagamore Parkway eastbound bridge over the Wabash River, the span lengths between piers, and the dead loads at the bottom of each pier (Han, Prezzi, et al., 2020).

3. INSTRUMENTATION OF THE BRIDGE PIER AND PILES

The bridge pier and its foundation elements were instrumented with strain gauges as part of SPR-4165 (*Verification of Bridge Foundation Design Assumptions and Calculations*). Based on the data collected from the strain gauges, the loads transferred from the superstructure to the foundation elements were obtained. Figure 3.1 shows the details of the instrumentation scheme of the bridge pier and the piles supporting it. At the head of each pile, a pair of arc-weldable, vibrating-wire (VW) strain gauges (Geokon model 4000) were welded on diametrically opposite sides (east and west sides) to cancel out any bending moment that may occur during loading. At a pier cross section 3-ft above its base, ten rebar (sister-bar) vibrating-wire strain gauges (Geokon model 4911) and five concrete-embedded vibrating-wire strain gauges (Geokon model 4200) were installed. In Figure 3.1, the blue dots at the center represent the concrete-embedded strain gauges and the red dots along the wall faces represent the rebar strain gauges. To calculate the total axial load carried by the pier, the pier cross section was divided into fifteen tributary areas, each associated with one of the strain gauges (Han, Prezzi, et al., 2020). The settlement of the bridge pier 7 was measured 2–3 times per month using a TOPCON DL-101C digital optical level and a bar code sticker attached to the pier.

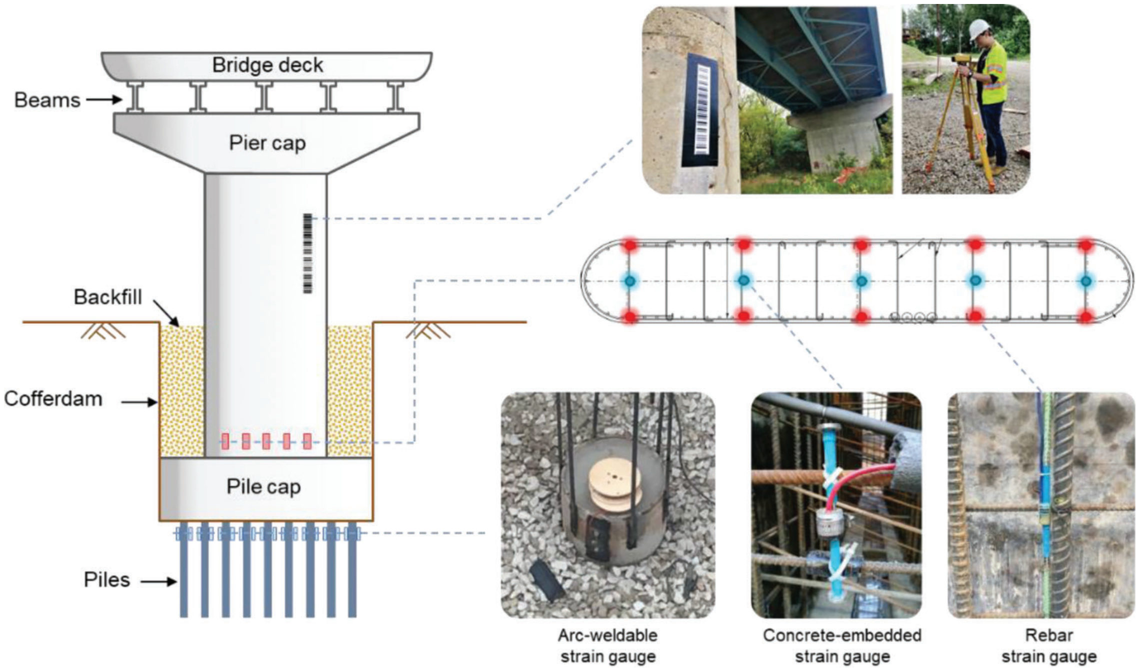


Figure 3.1 A sketch of the structural and foundation components of pier 7 with the locations of the strain gauges installed in the bridge pier and on the foundation elements and the barcode used for settlement measurements (modified after Han, Marashi, et al., 2020).

4. WIRELESS MEASUREMENT SYSTEM

In order to ensure continuous real-time monitoring of the Sagamore Parkway Bridge pier, a solar powered Data Acquisition (DAQ) system with wireless capability was used to collect the data. Figure 4.1 shows a schematic view of the methodology employed to collect the data remotely. The DAQ system is a Geokon model 8600 unit with Campbell Scientific (CS) CR6 series data logger, a Sierra Airlink RV50 LTE wireless modem, and two PowerUp BSP-2012 solar panels with two Power Sonic PS-1270 batteries connected to each solar panel. The research team also used three Geokon model 8032 16-channel multiplexers to extend the number of channels on the CS CR6 series data logger to be able to collect data from all the strain gauges and the external ambient temperature sensor. All the strain gauges installed in the bridge pier and on the pile heads, and the external ambient temperature sensor are connected to the data logger through the multiplexers. The readings are collected and stored in the data logger at 5-minute intervals. The wireless modem is used to

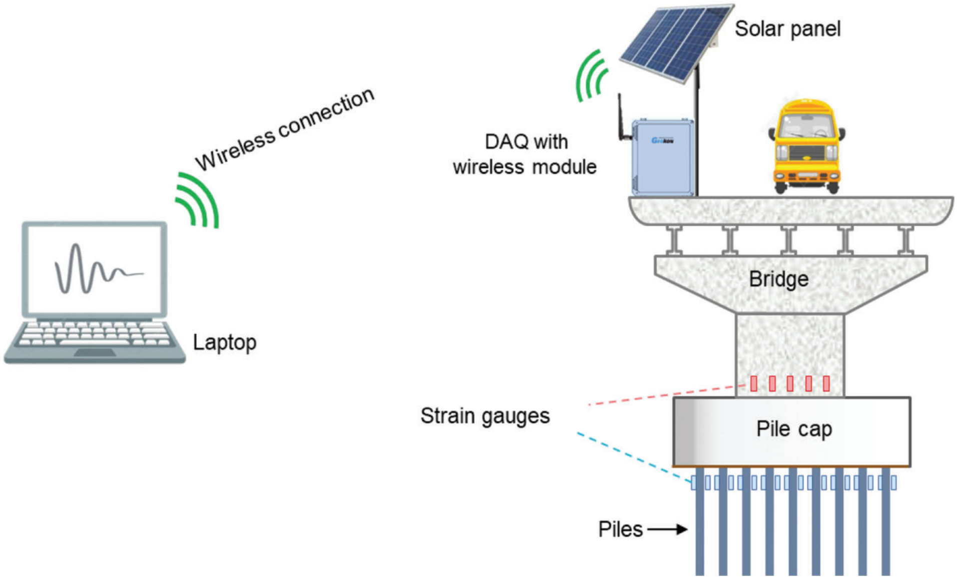


Figure 4.1 Scheme for the wireless real-time measurement of the load transfer in the bridge.

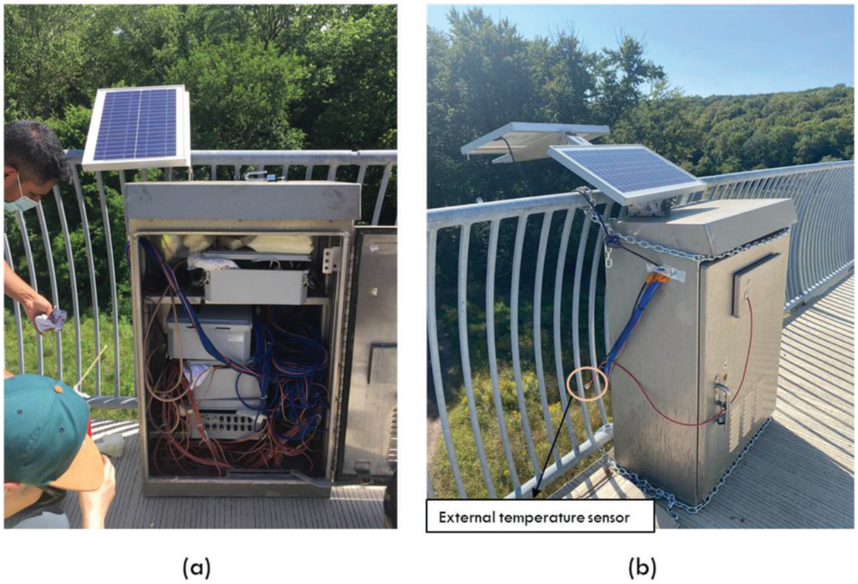


Figure 4.2 Photos of the cabinet secured to the bridge deck: (a) DAQ and multiplexers with cables coming from the strain gauges installed on the bridge pier and piles and (b) location of the external temperature sensor.

TABLE 4.1
Specifications of the equipment used in the project

Equipment	**Specifications**
Geokon model 8600 Data Acquisition (DAQ) unit	Accuracy: ±(0.04% of reading + 2 microvolts), 0°C–40°C (analog), ±0.013% of reading (vibrating wire) Resolution: 50 nV (±200 mV range, differential measurement, input reversal, 5 Hz f_{N1}) (analog); 0.001 Hz RMS (frequency)
Geokon model 8032 16-channel multiplexer	Switching current: 1 A Contact resistance: 0.1 Ω Insulation resistance: > 1G Ω Switch life: > 200,000 cycles Temperature range: -40°C to 60°C
PowerUp BSP-2012 solar panel	Rated (Pr) and peak (Pmpp) power: 20 W Peak Power Voltage (Vmpp) and current (Impp): 17.3 V and 1.20 A Open Circuit Voltage (Voc): 21.7 V Short Circuit Current (Isc): 1.30 A
Power Sonic PS-1270 battery	Nominal voltage: 12 v Capacity @20HR: 7.0 Ah Capacity @10HR: 6.5 Ah
Sierra Airlink RV50 LTE modem	Connection type: Cat 6. LTE-A Pro (300/50 Mbps), HSPA+

transfer data remotely to the research team's PC through the LTE network using the LoggerNet software developed by Campbell Scientific, Inc. The entire system is powered by two solar panels and two batteries. The solar panels supply power to the DAQ system and charge the batteries. The system has the capability of switching automatically between the solar power and battery power or use both sources of power as needed. The entire DAQ system is stored inside a cabinet secured to the bridge deck on the pedestrian side of the bridge (see Figure 4.2). The specifications of the equipment used are summarized in the Table 4.1.

5. MEASUREMENT RESULTS

Based on the continuous data collected remotely, additional data points were added to the load-settlement curve of the bridge pier obtained from the data reported in SPR-4165. In addition, the contribution of the pile cap in carrying the load from the superstructure was assessed from July 2021 to November 2021. The effects of ambient temperature changes and Wabash River water level fluctuations on the load transferred to the bridge pier and its foundations were also investigated.

5.1 Load-Settlement Response of the Bridge Pier

Figure 5.1 shows the different stages of the construction of the Sagamore Parkway Bridge with the total load transferred to the bridge pier and its foundations versus the settlement of pier 7 since completion of stage 2 (construction of the pier cap and backfilling of the cofferdam). Settlement measurements started from stage 2 onwards due to limited accessibility to the bridge pier in the initial stages of the bridge construction (Han, Prezzi, et al., 2020). To calculate the total axial load carried by the pier, the cross section of the pier was divided into fifteen tributary areas, each one associated with one of the strain gauges (as shown in Figure 3.1). The total axial load Q_{pier} in the pier was calculated as follows:

$$Q_{\text{pier}} = \sum_{i=1}^{15} E_i \varepsilon_i A_i \qquad \text{(Eq. 5.1)}$$

where E_i is the equivalent Young's modulus of the tributary area i, ε_i is the strain reading from the strain gauge in the tributary area and A_i is the tributary area. The equivalent Young's modulus E_i is calculated as:

$$E_i = (E_S A_{Si} + E_C A_{Ci})/A_i \qquad \text{(Eq. 5.2)}$$

where A_{Ci} and A_{Si} are the areas of the concrete and steel in the i^{th} tributary area A_{i}.

The load-settlement response of pier 7 from the end of stage 2 to the end of the bridge construction is almost linear. The last two data points in Figure 5.1 shows the readings taken on July 2, 2021, and November 8, 2021. No significant change in the load or the settlement of the pier was observed as expected considering that it has been 3 years since the completion of the bridge.

5.2 Load Transfer from the Bridge Pier to the Foundation Piles

With the data collected from the strain gauges installed in pier 7 and all the 15 piles supporting it, the load transfer from the superstructure to the foundation elements was obtained at different stages during and after the bridge construction from December 2017 to November 2021. The total load Q_{total} on the pile cap is balanced by the load Q_{pg} carried by all the 15 piles in the pile group and the load Q_{cap} carried by the soil under the pile cap. The total vertical load on the pile cap has two components: the vertical load that comes from the superstructure through the bridge pier (obtained from the strain gauges installed near the base of the pier column) and the gravity load of the backfill in the cofferdam (estimated based on the unit weight of the backfill). The difference between the two curves (representing Q_{total} and Q_{pg}) shown in Figure 5.2 is equal to the load Q_{cap} carried by the soil below the pile cap. In the most recent measurements, the load applied on the pile cap is approximately 4,100 kips, while that in the piles is about 3,400 kips. Figure 5.2 compares these measurements.

5.3 Load Bearing Capacity of the Pile Cap

Figure 5.3 shows the $Q_{\text{pg}}/Q_{\text{total}}$ and $Q_{\text{cap}}/Q_{\text{total}}$ ratios measured during different construction stages of the

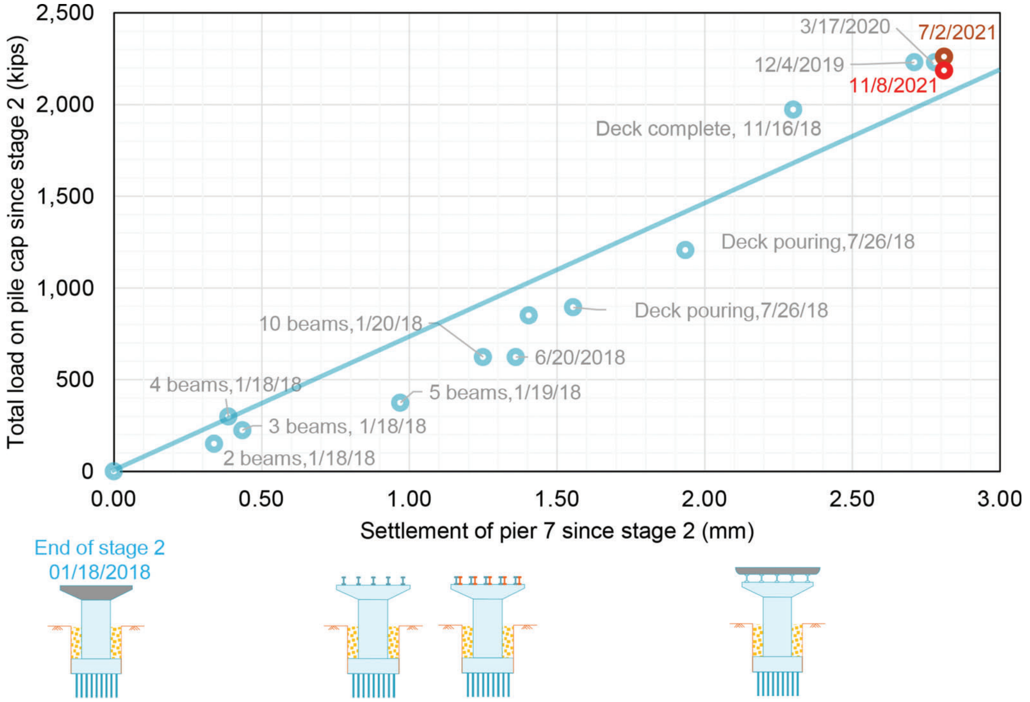


Figure 5.1 Total load applied on the pile cap versus the corresponding settlement of pier 7 measured at different stages during and after bridge construction (modified after Han, Marashi, et al., 2020).

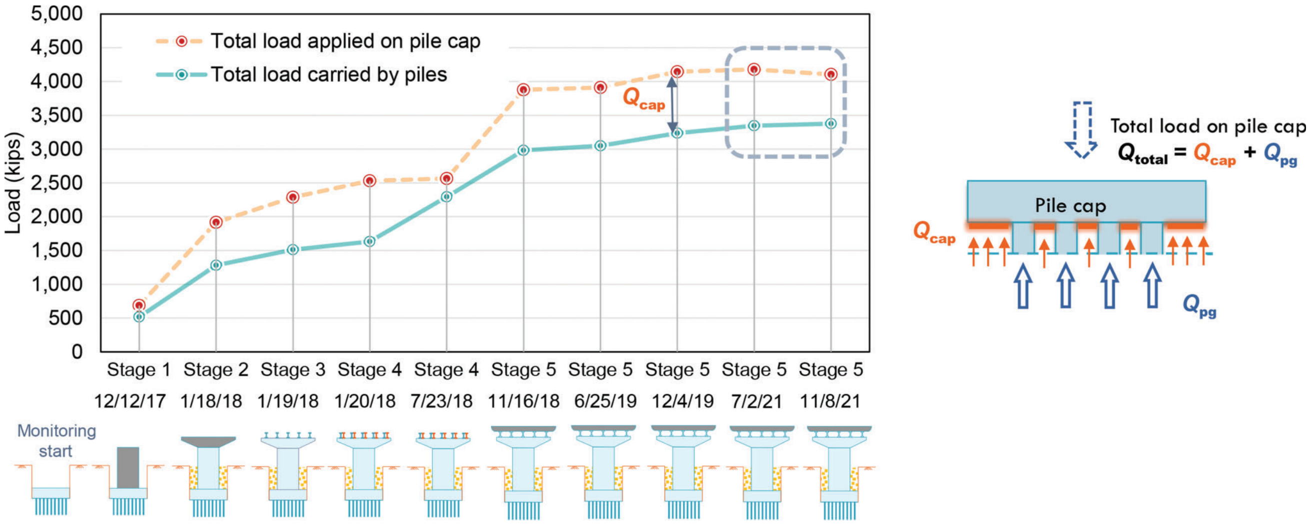
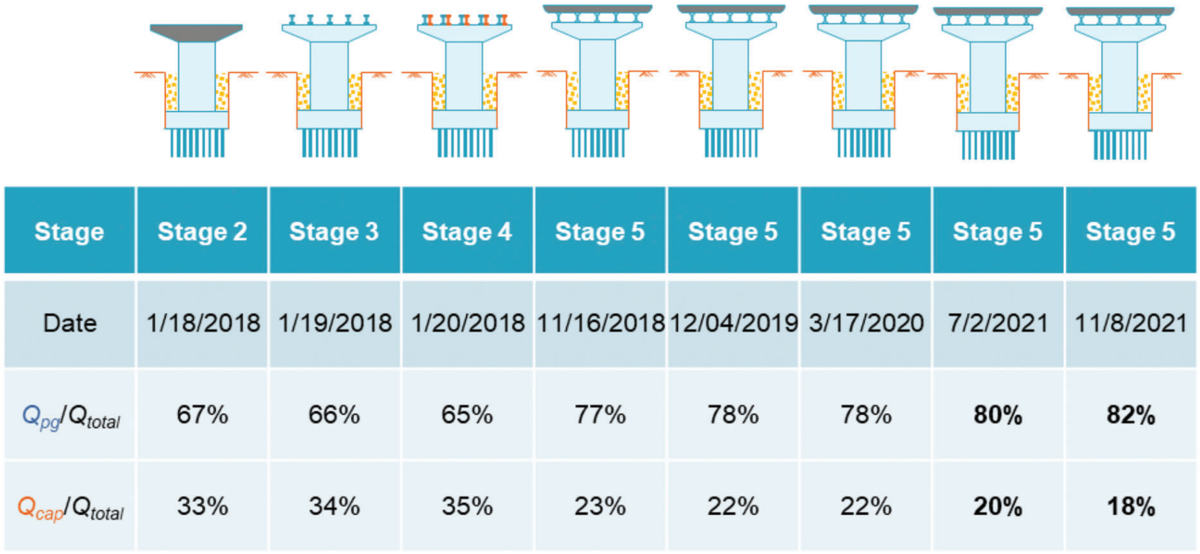


Figure 5.2 Total load applied on the pile cap and total load carried by the piles in the group measured at different stages during and after the bridge construction (modified after Han, Marashi, et al., 2020).



Stage	Stage 2	Stage 3	Stage 4	Stage 5	Stage 5	Stage 5	Stage 5	Stage 5
Date	1/18/2018	1/19/2018	1/20/2018	11/16/2018	12/04/2019	3/17/2020	7/2/2021	11/8/2021
Q_{pg}/Q_{total}	67%	66%	65%	77%	78%	78%	**80%**	**82%**
Q_{cap}/Q_{total}	33%	34%	35%	23%	22%	22%	**20%**	**18%**

Figure 5.3 Total load applied on the pile cap and total load carried by the piles in the group measured at different stages during and after the bridge construction (modified after Han, Marashi, et al., 2020).

bridge pier. These ratios change slightly during the construction of the bridge; however, after the bridge construction was complete, the contribution of the pile cap has been quite stable around 20%, with some minor variations that may be attributed to some load redistribution between the bridge piers and to water level fluctuations in the Wabash River. Figure 5.4 shows the ratios Q_{pg}/Q_{total} and Q_{cap}/Q_{total} for a period of about 5 months from July through November 2021. The pile cap contributes significantly ($\approx$ 20%) to the load carrying capacity of the foundation. This agrees with the findings reported by Han, Salgado, et al., (2019) and Han, Prezzi, and Salgado (2021) obtained from finite element analyses.

5.4 Effect of Temperature Sensor Location on Ambient Temperature Measurements

Initially, a built-in temperature sensor in the DAQ system stored inside the DAQ cabinet secured at the bridge deck was used to obtain temperature measurements. It was observed that measurements made in this manner were not consistent with the temperature from the weather report collected from the timeanddate.com website, which archives the weather data collected from the weather station located at the Purdue University Airport, West Lafayette, IN. Figure 5.5 shows the difference between the measured temperature from the sensor inside the cabinet and the temperature data

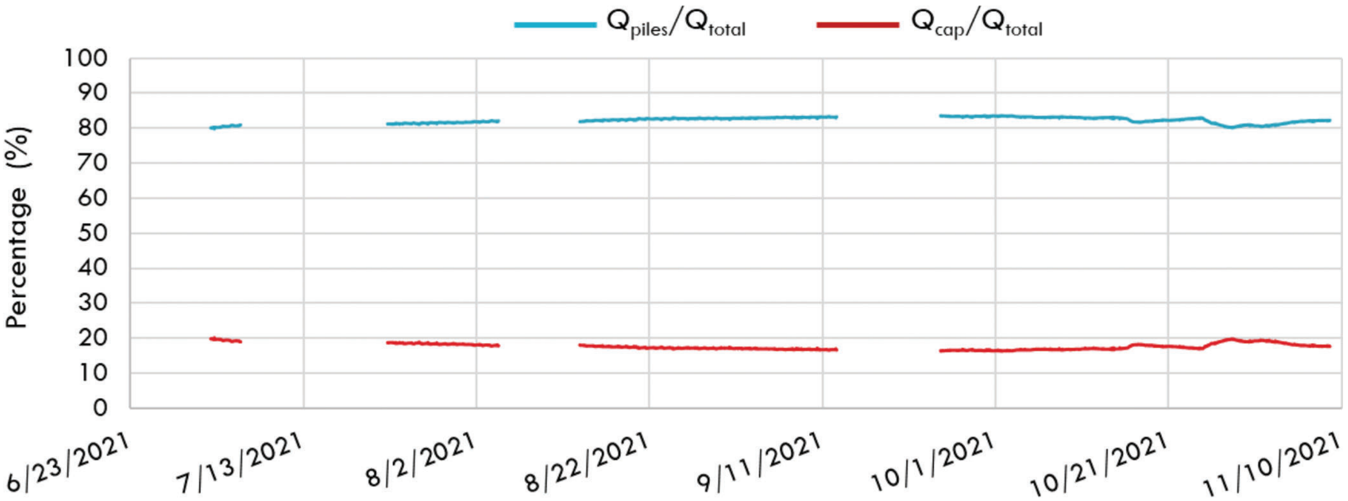


Figure 5.4 Percentage of the total load carried by the piles in the group and pile cap during the period of wireless monitoring (the missing data is caused by maintenance of the DAQ system).

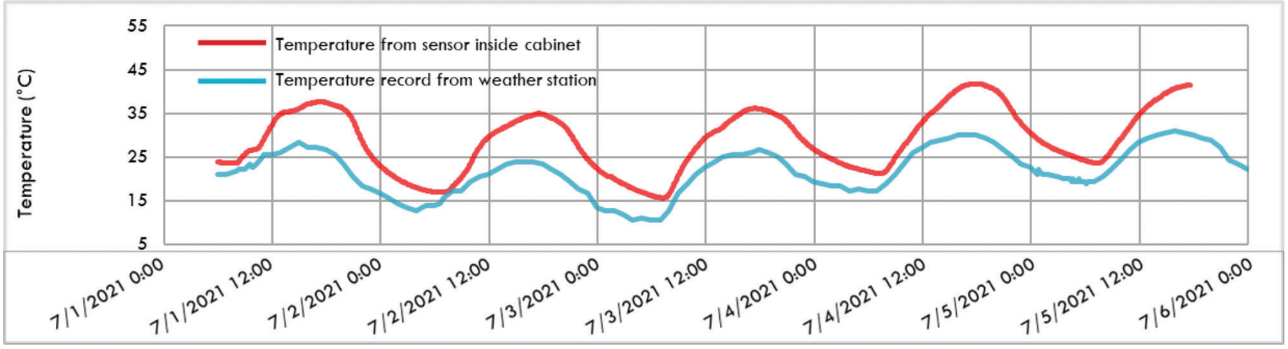


Figure 5.5 Temperature measurements from the sensor placed inside the DAQ cabinet and the temperature data obtained from the time and date website (https://www.timeanddate.com/weather/usa/lafayette-in/hourly).

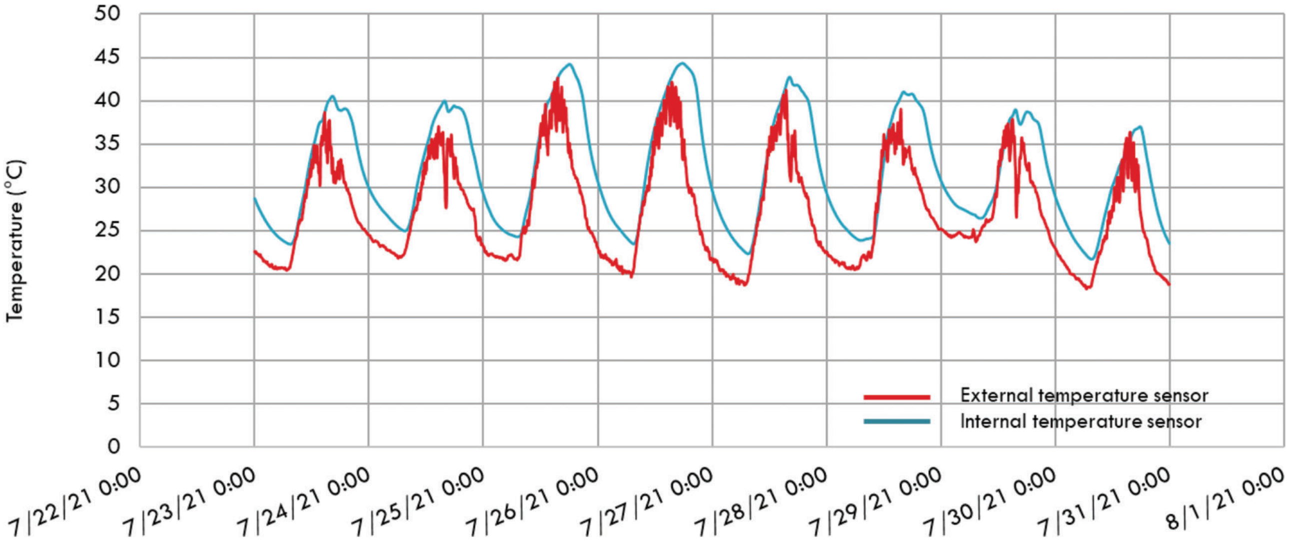


Figure 5.6 Difference in temperature readings recorded by external and internal temperature sensors.

obtained from the time and date website (https://www.timeanddate.com/weather/usa/lafayette-in/hourly). To have accurate temperature measurements, an external temperature sensor was installed outside the cabinet. The temperature readings from this new sensor were less than the internal temperature sensor (see Figure 5.6) but still not in agreement with the temperature data collected from the time and date website (https://www.timeanddate.com/weather/usa/lafayette-in/hourly, see Figure 5.7). The data presented in this report is based on the temperature data collected from the timeanddate.com website, unless mentioned otherwise.

5.5 Bending Moment Increments in the Bridge Pier and Foundation Piles Due to Daily Ambient Temperature Cycles

Temperature cycles cause an increment in the bending moments carried by the bridge pier and the piles. Figure 5.8 illustrates the sign convention used to define whether the bending moment increment is positive or negative. A clockwise bending moment, in the direction towards the end bent 8, is considered as a positive bending moment. As the temperature increases, the bridge deck expands and pushes against pier 7, generating a positive bending moment increment in the bridge pier. The bending moment increment is calculated as follows:

$$\Delta M = (EI)_{\text{pier}} \frac{\Delta\varepsilon_{\text{E}} - \Delta\varepsilon_{\text{W}}}{d} \quad \text{(Eq. 5.3)}$$

where $(EI)_{\text{pier}}$ is the composite bending stiffness of the bridge pier, $(\Delta\varepsilon_{\text{E}} - \Delta\varepsilon_{\text{W}})$ is the difference in strain increment measured on the east and west side of the bridge pier (considering compressive strain as positive), and d is the width of the pier (=3.5 feet).

Figure 5.9 shows the bending moment increments in the bridge pier and foundation piles plotted together with temperature readings from July 2021 to November 2021. The variation in the bending moment increments follows a trend which is identical to the local day/night temperature cycles. As the temperature rises during the daytime, the bridge deck expands and generates a lateral force towards pier 7, creating a positive bending moment, as explained earlier. However, the bridge deck contracts due to the temperature drop during the night, and causes a negative bending moment increment in pier 7.

In Figure 5.10 and Figure 5.11, the bending moment increments carried by the piles is plotted together with the bending moment increments carried by the pier for the first week of July and November, respectively. For illustration purposes, using the reference strains recorded in the first day of the month, it can be observed that the bending moment increments carried by the pier are greater than the bending moment increments carried by the piles for both the weeks considered in July and November 2021. The percentage of the bending moment increments carried by the piles is plotted in Figure 5.12 and Figure 5.13 for the two illustration weeks; this percentage is approximately 60% for both these weeks.

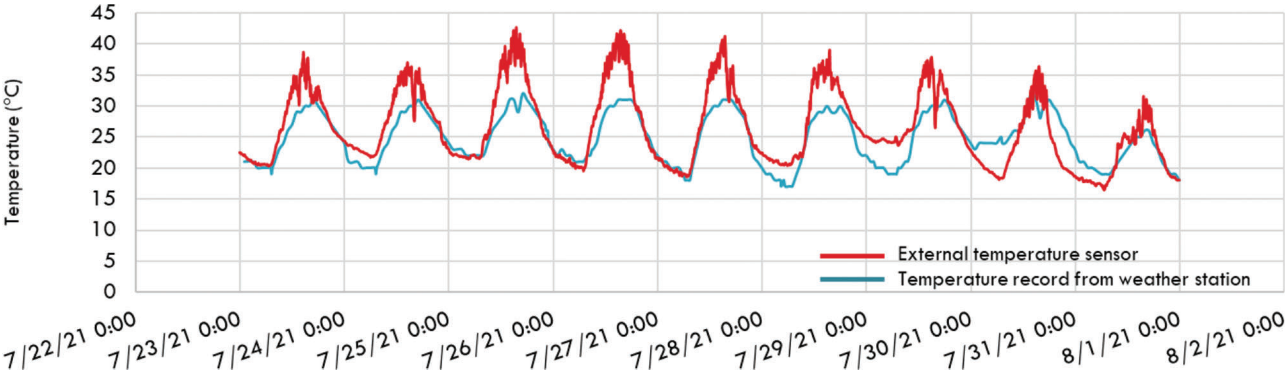


Figure 5.7 Difference in temperature readings between the external temperature sensor and the temperature data obtained from the time and date website at the Purdue University Airport weather station (https://www.timeanddate.com/weather/usa/lafayette-in/hourly).

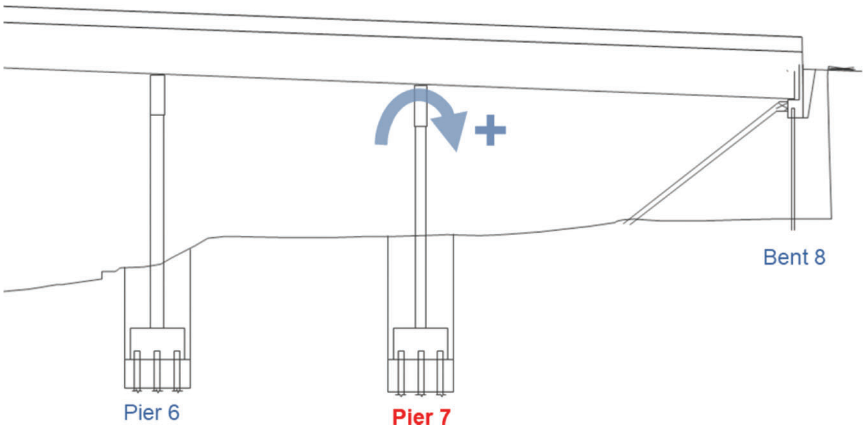


Figure 5.8 Sign convention for the bending movement in pier 7 (looking from south to north).

Figure 5.9 Bending moment increment in the bridge pier and piles versus temperature.

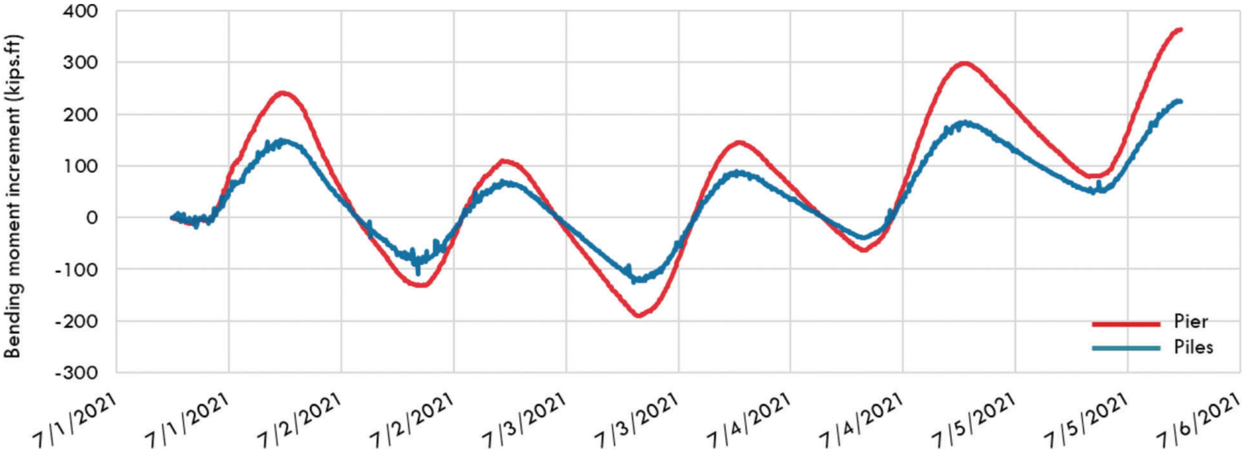


Figure 5.10 Bending moment increment carried by the bridge pier and the piles for the first week of July 2021.

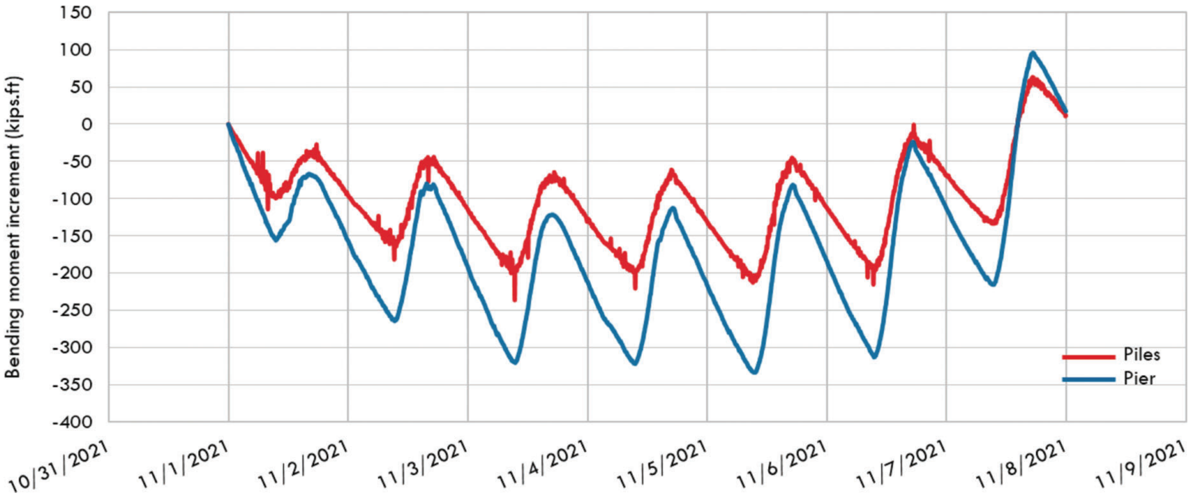


Figure 5.11 Bending moment increment carried by the bridge pier and the piles for the first week of November 2021.

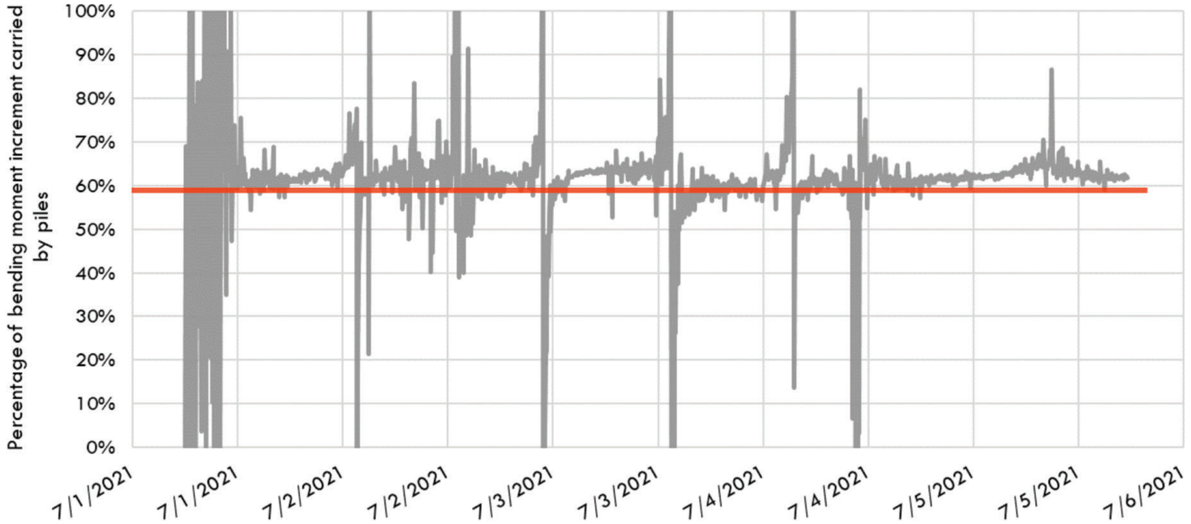


Figure 5.12 Percentage of bending moment increment carried by the piles for the first week of July 2021.

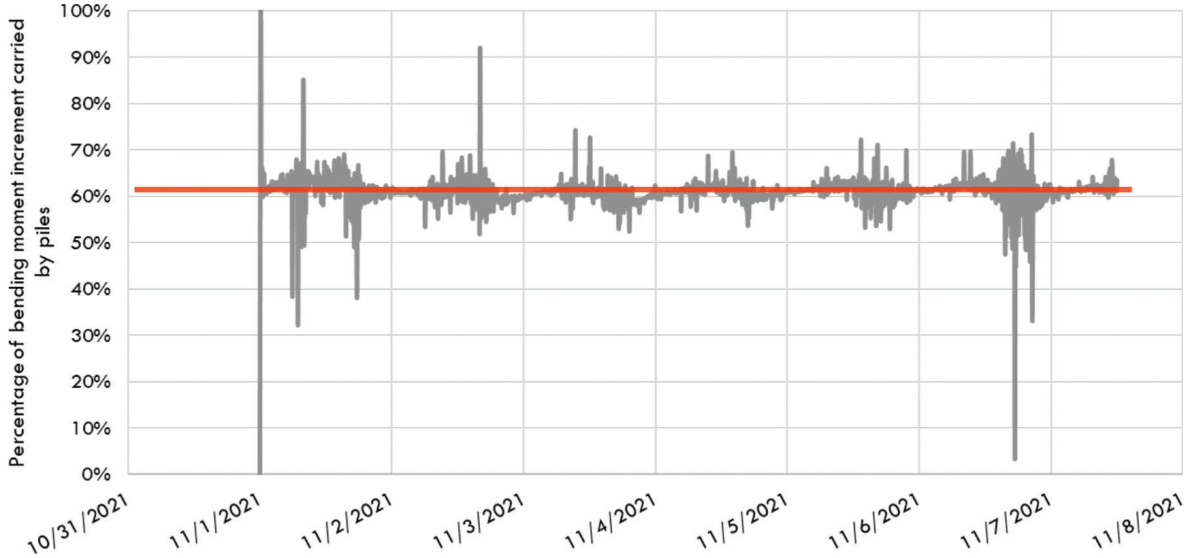


Figure 5.13 Percentage of bending moment increment carried by the piles for the first week of November 2021.

5.6 Load Increments at the Pile Heads Due to Daily Ambient Temperature Cycles

Figure 5.14 shows the layout of the 3 × 5 pile group of pier 7 and a cross section of the pile cap. The pile group is further subdivided into east, west and middle subgroups depending on the position of the piles.

The average load increments at the pile heads were calculated for the three subgroups using the data collected in the reference weeks (first week of July and November). Figure 5.15 shows the average load increments in the pile subgroups for the first week of July. Following the sign conventions, as explained above for the positive bending moment, it is interesting to note that the contrasting response of east subgroup and the west subgroup in supporting the load increment due to bridge deck expansion/contraction resulting from ambient temperature variations. The response of the middle subgroup lies in between its neighboring sub-groups. A similar trend is observed in the first week of November (see Figure 5.16), but due to lower temperatures (contraction of the bridge deck generating negative bending moment), the west subgroup is carrying continuously higher portion of the load increment than the east subgroup. The contribution of the middle subgroup again lies in between its neighboring subgroups.

5.7 Impact of the Wabash River Water Level Fluctuations on the Loads Transferred to the Bridge Pier

In addition to temperature cycles, the changes in the ground water level of the Wabash River have an impact on the load transfer from the superstructure to the bridge pier and the foundation elements. The Wabash

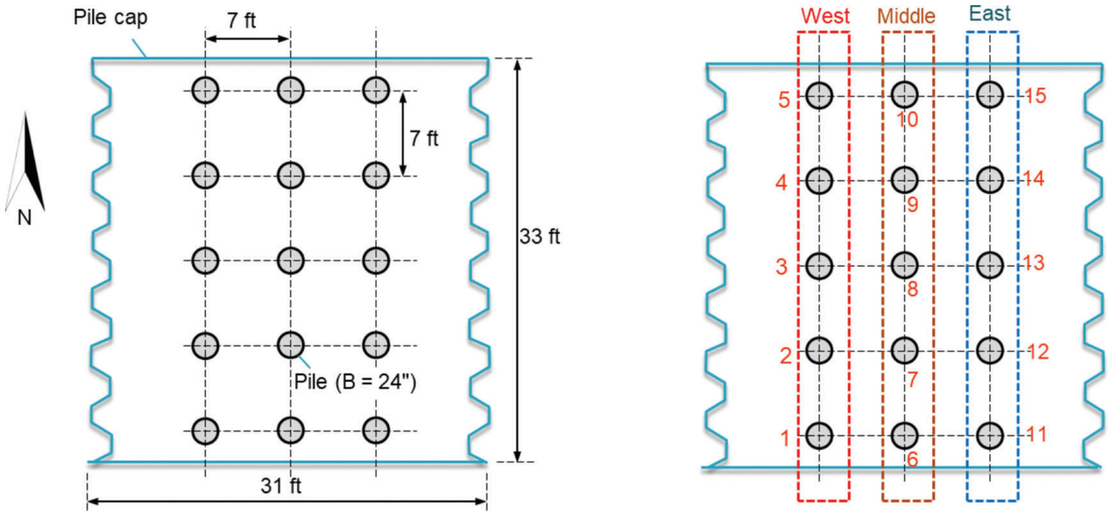


Figure 5.14 Layout of the pile group and cross section of the pile cap under pier 7.

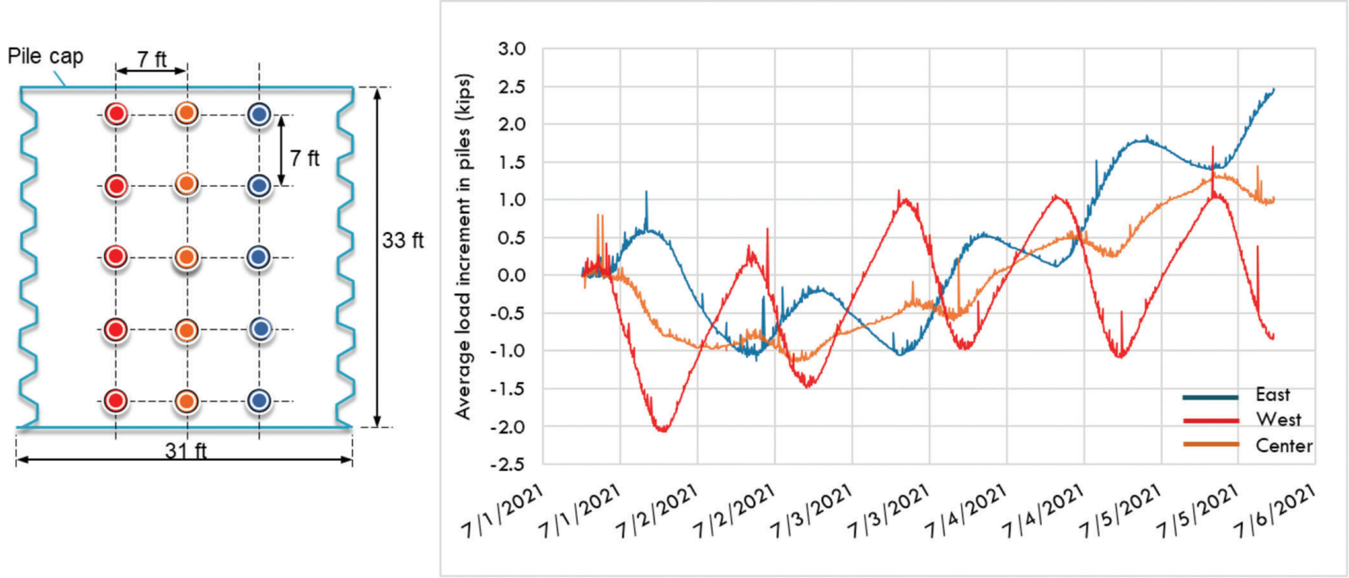


Figure 5.15 Load increments at the pile heads for the first week of July 2021.

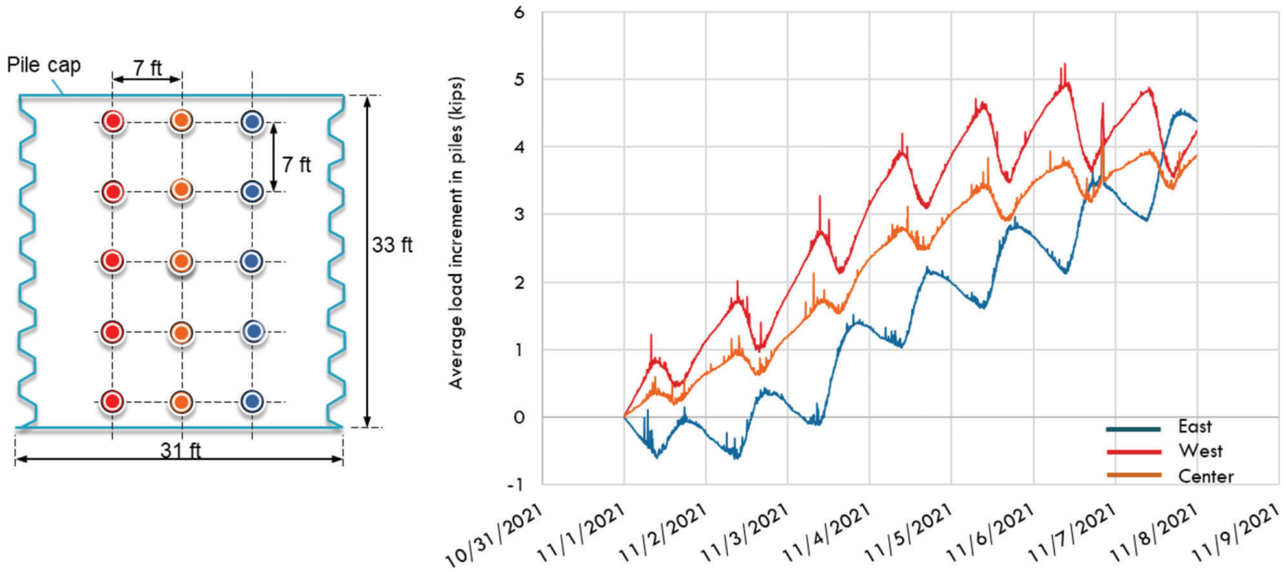


Figure 5.16 Load increments at the pile heads for the first week of November 2021.

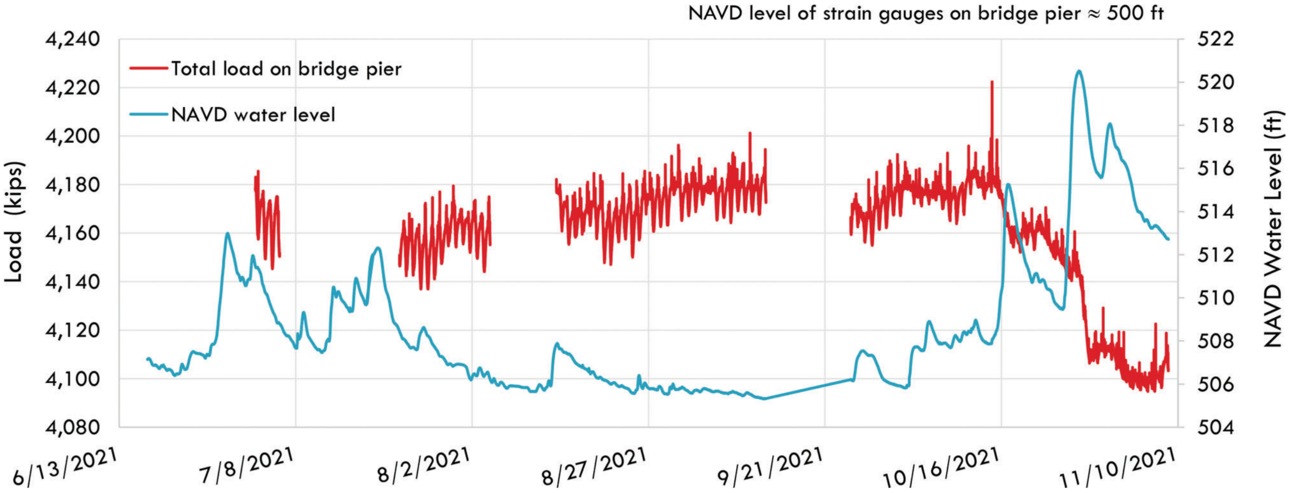


Figure 5.17 Variations in the load carried by the bridge pier with the change in water level in the Wabash River.

River water level data was obtained from the USGS (United States Geological Survey) Water Data website (https://waterdata.usgs.gov/monitoring-location/03335500/#parameterCode=00065&period=P7D). The gauge height readings are taken at a USGS water level monitoring station (location 03335500) located approximately 1 mile downstream from the Sagamore Parkway Bridge site. Figure 5.17 shows the total load on the bridge pier versus water level readings using as reference to the North American Vertical Datum (NAVD) over a period of about 5 months from July to November 2021. The fluctuations of the water level in the Wabash River affected the load carried by the bridge pier. A rise in the water level of the river above the elevation of the strain gauges in the bridge pier results in a reduction in the total load measured at that location. The reduction in the total load carried by the bridge pier is due to some possible load redistribution between bridge piers and the buoyancy effects resulting from the rise in the water level. This was correctly picked up by the strain gauges, as shown in the Figure 5.17.

The load data presented in Figure 5.17 has some discontinuities because of the data loss. The data loss is caused by vandalism and power supply issues during the data collection period; the former was solved by securing the cabin on the bridge rails, and the latter was solved by increasing the power capacity to ensure that the power source can supply the system during long cloudy seasons.

6. SUMMARY AND CONCLUSIONS

The construction of the eastbound Sagamore Parkway Bridge was completed in November 2018. The bridge pier 7 and its foundation elements were monitored in real time approximately for a period of 5 months. The data from the strain gauges and the temperature sensor were successfully collected every

5 minutes using the solar powered DAQ and then transferred remotely via a wireless cellular network to the research team's PC. The settlement of the bridge pier was measured periodically using a digital level and a polymer barcode sticker attached on the bridge pier.

The data shows that there is no significant change in the load-settlement response of pier 7 after the construction of the bridge. The pile cap is carrying approximately 20% of the total load transferred from the superstructure. The daily cycles of the ambient temperature have an impact on the load transfer to the foundations. As the bridge deck expands because of the increase in temperature during the day, a moment is produced and transferred to the bridge pier and the piles. The general trend in the fluctuations in the daily temperature values matches well with the variations in the bending moments increments in the bridge pier and the piles. It was observed that the responses of the pile sub-groups were sensitive to their orientation with respect to the resultant lateral load generated by bridge deck expansion/contraction. A slight drop in the load carried by the bridge pier is observed in the periods of high water level in the Wabash River, which indicates that upward acting buoyant forces causes load redistribution between the bridge piers and also within the pier and its supporting pile group.

The results of the bridge monitoring have shown that the bridge has performed well since construction. There are no significant changes in terms of the bridge pier settlement, and there is an active contribution from the pile cap in supporting the applied loads after 3 years of its construction. It is recommended that the long-term monitoring using a wireless module as done in this project to be continued to obtain valuable data to compare the changes in different seasons.

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About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

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