Implementation of Recommendations for Eliminating Longitudinal Median Joints in Wide Bridges

Final Report
June 2022

BRIDGE ENGINEERING CENTER

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Iowa Highway Research Board
(IHRB Project TR-752)
Iowa Department of Transportation
(InTrans Project 18-660)

About the Bridge Engineering Center

The mission of the Bridge Engineering Center (BEC) is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

About the Institute for Transportation

The mission of the Institute for Transportation (InTrans) at Iowa State University is to save lives and improve economic vitality through discovery, research innovation, outreach, and the implementation of bold ideas.

Iowa State University Nondiscrimination Statement

Iowa State University does not discriminate on the basis of race, color, age, ethnicity, religion, national origin, pregnancy, sexual orientation, gender identity, genetic information, sex, marital status, disability, or status as a US veteran. Inquiries regarding nondiscrimination policies may be directed to the Office of Equal Opportunity, 3410 Beardshear Hall, 515 Morrill Road, Ames, Iowa 50011, telephone: 515-294-7612, hotline: 515-294-1222, email: eooffice@iastate.edu.

Disclaimer Notice

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the sponsors.

The sponsors assume no liability for the contents or use of the information contained in this document. This report does not constitute a standard, specification, or regulation.

The sponsors do not endorse products or manufacturers. Trademarks or manufacturers' names appear in this report only because they are considered essential to the objective of the document.

Iowa DOT Statements

Federal and state laws prohibit employment and/or public accommodation discrimination on the basis of age, color, creed, disability, gender identity, national origin, pregnancy, race, religion, sex, sexual orientation or veteran's status. If you believe you have been discriminated against, please contact the Iowa Civil Rights Commission at 800-457-4416 or Iowa Department of Transportation's affirmative action officer. If you need accommodations because of a disability to access the Iowa Department of Transportation's services, contact the agency's affirmative action officer at 800-262-0003.

The preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its "Second Revised Agreement for the Management of Research Conducted by Iowa State University for the Iowa Department of Transportation" and its amendments.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Iowa Department of Transportation.

Technical Report Documentation Page

1. Report No.	**2. Government Accession No.**	**3. Recipient's Catalog No.**
IHRB Project TR-752		

4. Title and Subtitle
Implementation of Recommendations for Eliminating Longitudinal Median Joints in Wide Bridges

5. Report Date
June 2022

6. Performing Organization Code

7. Author(s)
Justin M. Dahlberg (orcid.org/0000-0002-6184-4122), Zhengyu Liu (orcid.org/0000-0002-7407-0912), and Brent M. Phares (orcid.org/0000-0001-5894-4774)

8. Performing Organization Report No.
InTrans Project 18-660

9. Performing Organization Name and Address
Bridge Engineering Center
Iowa State University Project
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Organization Name and Address
Iowa Highway Research Board
Iowa Department of Transportation
800 Lincoln Way
Ames, IA 50010

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code
IHRB Project TR-752

15. Supplementary Notes
Visit https://intrans.iastate.edu/ for color pdfs of this and other research reports.

16. Abstract

Longitudinal joints are thought to provide relief from expansion and contraction of the bridge deck resulting from temperature change, shrinkage, and live loads. Historically, however, these joints have been known to leak, allowing chloride-laden water to reach the bottom of the deck overhang and even the exterior girders.

One of the primary conclusions from the previous Phase I project was that the development of cracking in bridge decks appears to be less dependent on the total width of the deck and more dependent on restraint of the abutment to temperature changes and, in particular, temperature gradients. Based on the results of that research, a 115 ft long, 228 ft wide, bridge in Black Hawk County, Iowa, was selected and designed to incorporate a thermal isolation barrier.

The objective of this research was to follow and document the design, construction, and performance of the bridge in Black Hawk County with a specific focus on the success of the deck crack mitigation efforts. To achieve this objective, the newly constructed bridge on Viking Road over IA 58 was selected for this study.

A nearly two-year-long monitoring period enhanced by multiple bridge inspections was conducted. In addition, an analytical study was conducted to investigate the efficacy of the isolation barrier on resisting the cracking at the end of the deck for an integral abutment bridge.

The results confirmed the findings from the Phase I research that development of cracking in bridge decks seems less dependent on the total width of the deck. The finite element model results indicated the maximum deck strain to be 46% greater without the effects of the thermal isolation barrier. This indicated that, without the thermal isolation barrier, the Viking Road Bridge could see cracking at the end of its deck.

The researchers recommend the use of a thermal isolation barrier between the abutment and backfill soils for wide integral abutment bridges as one way to lengthen the service life of these bridge decks while reducing maintenance, rehabilitation, and/or replacement costs as well.

17. Key Words
integral bridge abutments—longitudinal median joints—thermal isolation barriers—wide bridges

18. Distribution Statement
No restrictions.

19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified.	Unclassified.	69	NA

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

IMPLEMENTATION OF RECOMMENDATIONS FOR ELIMINATING LONGITUDINAL MEDIAN JOINTS IN WIDE BRIDGES

Final Report
June 2022

Co-Principal Investigators
Brent M. Phares, Bridge Research Engineer
Katelyn S. Freeseman, Former Acting Director
Bridge Engineering Center, Iowa State University

Primary Researchers
Justin M. Dahlberg, Research Engineer
Zhengyu Liu, Research Engineer
Bridge Engineering Center, Iowa State University

Authors
Justin M. Dahlberg, Zhengyu Liu, and Brent M. Phares

Sponsored by
Iowa Highway Research Board and
Iowa Department of Transportation
(IHRB Project TR-752)

Preparation of this report was financed in part
through funds provided by the Iowa Department of Transportation
through its Research Management Agreement with the
Institute for Transportation
(InTrans Project 18-660)

A report from
Bridge Engineering Center
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
https://intrans.iastate.edu/

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The research team would like to acknowledge the Iowa Highway Research Board (IHRB) and Iowa Department of Transportation (DOT) for sponsoring this research. They would like to thank the following technical advisory committee (TAC) members with the Iowa DOT Bridges and Structures team:

- Ahmad Abu-Hawash, formerly chief structural engineer
- Michael Nop, bridge project development engineer
- Lilli Yang, project review coordinator

EXECUTIVE SUMMARY

Research Objective, Focus, and Scope

The primary objective of this research was to follow and document the design, construction, and performance of a bridge in Black Hawk County with a specific focus on the success of the deck crack mitigation efforts. The primary objective was reached through the following efforts:

- Review the literature from the Phase I research work with respect to bridge width limitations and search the current research literature further about the thermal effects on bridge structures
- Perform field monitoring on a wide bridge constructed in Black Hawk County
- Conduct an analytic study on the thermally induced effect on the wide bridge
- Synthesize the findings to develop further recommendations for adoption

Problem Statement

Longitudinal bridge deck joints are commonly used in cases where the roadway carries a larger than typical number of traffic lanes necessitating a greater bridge deck width. The Iowa Department of Transportation (DOT) requires the use of longitudinal bridge joints in wide bridges with the hopes of reducing or eliminating the cracking that has been observed in wide bridges constructed without longitudinal joints.

The longitudinal joints are thought to provide relief from expansion and contraction of the bridge deck resulting from temperature change, shrinkage, and live loads. Historically, however, these joints have been known to leak, allowing chloride-laden water to reach the bottom of the deck overhang and even the exterior girders. This has resulted in cases of premature deterioration.

The problem is most severe when the joint is narrow and/or located between median barrier rails where the water can be trapped for long periods of time. Weathering steel bridges are particularly sensitive to this situation as the protective patina may never naturally form. This is a situation where the elimination of one problem (cracking associated with wide bridges) has created a second problem (a problematic longitudinal joint).

Project Background

The Phase I Iowa Highway Research Board project (IHRB project TR-661) was completed to determine the maximum width of a continuous deck that can be used without negatively impacting performance. One of the primary conclusions of this work was that the development of cracking in bridge decks seems less dependent on the total width of the deck and more dependent on internal restraint of the abutment when significant temperature gradients exist between the bridge deck and the very rigid abutment.

Based on the finite element (FE) results from that study, it was proposed that an effective solution to reduce cracking in the deck might be to place a thermal isolation barrier between the backfill soils and the back side of the abutment, thus maintaining closer temperatures within the abutment and bridge deck.

Research Description

The objective of this research was to follow and document the design, construction, and performance of a newly constructed bridge in Black Hawk County with a specific focus on the success of the deck crack mitigation efforts. To achieve this objective, the bridge on Viking Road over IA 58 was selected to investigate the effects of a thermal isolation barrier.

The bridge was designed with a width of 228 ft, which is much greater than the maximum width of 60 ft before the use of a longitudinal joint is required per the 2012 Iowa Bridge Design Manual. The bridge deck had no longitudinal expansion joints, only closure pours between adjacent deck pours, in which the deck reinforcement was continuous.

Using the recommendations from the previous research, a thermal isolation barrier was used between the backfill soils and the abutment.

A more than two-year-long monitoring period followed the completion of construction using numerous thermistors and strain gauges at various abutment and deck locations. Additionally, periodic visual inspections were completed to identify if any deck cracks were forming.

In addition, an analytical study was conducted using FE models to investigate the efficacy of the isolation barrier on the bridge deck end structural behavior. The models were calibrated and validated using field-collected strain and temperature data.

Key Findings

By the end of May 2022, nearly three years after construction completion, no evidence of deck cracking existed.

With a thermal isolation barrier, the temperature difference between the back face and front face at each level of the abutment remained relatively close throughout the year with differences being less than 10°F in most cases. The value of the thermal isolation barrier was especially apparent when ambient temperatures changed very quickly and a greater temperature differential was more likely.

The FE model results indicated that significantly higher deck strains exist when a thermal isolation barrier is not in place to limit the temperature differential through the thickness of the abutment. In fact, the maximum deck strain was found to be 46% greater when the thermal isolation barrier was not included in the models.

Conclusions/Implementation Recommendations

The results support the findings from the Phase I research that the development of cracking in bridge decks appears less dependent on the total width of the deck and more the result of differential temperatures between the bridge deck and integral abutment. The results indicated that a thermal isolation barrier between the abutment and the backfill soils is effective for limiting temperature differentials, which thereby limits the potential for deck end cracking on integral abutment bridges.

The validated FE model analysis indicated that, without the barrier, the strain values at the deck ends of the Viking Road Bridge could exceed the calculated cracking strain of the concrete.

The researchers recommend the use of a thermal isolation barrier between the abutment and backfill soils for wide integral abutment bridges as one way to lengthen the service life of these bridge decks while reducing maintenance, rehabilitation, and/or replacement costs as well.

CHAPTER 1. INTRODUCTION

1.1 Background

Longitudinal bridge deck joints are commonly used in cases where the roadway carries a larger than typical number of traffic lanes necessitating a greater bridge deck width. The Iowa Department of Transportation (DOT) requires the use of longitudinal bridge joints in wide bridges with the hopes of reducing or eliminating the cracking that has been observed in wide bridges constructed without longitudinal joints.

The longitudinal joints are thought to provide relief from expansion and contraction of the bridge deck resulting from temperature change, shrinkage, and live loads. Historically, however, these joints have been known to leak, allowing chloride-laden water to reach the bottom of the deck overhang and even the exterior girders. This has resulted in cases of premature deterioration.

The problem is most severe when the joint is narrow and/or located between median barrier rails where the water can be trapped for long periods of time. Weathering steel bridges are particularly sensitive to this situation as the protective patina may never naturally form. This is a situation where the elimination of one problem (cracking associated with wide bridges) has created a second problem (a problematic longitudinal joint).

Iowa Highway Research Board (IHRB) project TR-661 (Phares et al. 2015), referred to as the Phase I research in this report, was completed to determine the maximum width of a continuous deck that can be used without negatively impacting performance. That project consisted of a combination of tasks including bridge inspections, finite element (FE) modeling, short-term bridge testing, long-term bridge testing, and the development of recommendations.

One of the primary conclusions of that work was that the development of cracking in bridge decks appears to be less dependent on the total width of the deck and more dependent on internal restraint of the abutment to the effects of temperature changes and, in particular, temperature gradients. The results also indicated that adding vertical expansion joints in the abutment do theoretically help to reduce the strain in the deck and control the maximum strain location in the deck, although adding these expansion joints presents other potentially troublesome issues.

Based on the Phase I finite element model (FEM) results, the researchers determined that an effective alternative solution to reduce cracking in the deck might be to place a thermal isolation barrier between the soil and back side of the abutment. As a result of this recommendation, a 115 ft long, 228 ft wide bridge in Black Hawk County was selected and designed to incorporate the thermal isolation barrier.

The bridge was planned for the December 19, 2017 letting with construction to follow as part of a large, multi-year project.

1.2 Objective and Approach

The primary objective of this research was to follow and document the design, construction, and performance of the bridge in Black Hawk County with a specific focus on the success of the deck crack mitigation efforts. The primary objective was reached through the following efforts:

- Review the literature from the Phase I research work with respect to bridge width limitations and the thermal effects on the bridge structures
- Perform field monitoring on a wide bridge constructed in Black Hawk County
- Conduct an analytic study on the thermally induced effect on the wide bridge
- Synthesize the findings to develop further recommendations for adoption

1.3 Research Plan

Task 1: Review project scope with technical advisory committee (TAC). The research team met with the project's TAC to review the project scope and work plan. An outline of the proposed work was presented and discussed with the TAC members. The purpose of this meeting was to discuss and clarify the scope of work, scheduling, and expected deliverables throughout the project and incorporate TAC input.

Task 2: Literature review. The Phase I research team focused on the findings and experience from other state DOT publications, National Cooperative Highway Research Program (NCHRP) project reports, the Transportation Research Record journal, and Transportation Research Board (TRB) proceedings to identify current work related to improving the performance of wide bridges. The majority of this task had been achieved via the previous study, although a new search of relevant material was conducted to include any recent developments on the topic. The previous Phase I work was reviewed and summarized. The literature on the requirements for bridge width limitations was searched and presented. In addition, a series of studies on the investigation of bridge temperature fields was found and reviewed.

Task 3: Field monitoring of Viking Road Bridge over IA 58. A more than two-year-long monitoring period was used for the newly constructed bridge on Viking Road over IA 58. An instrumentation system with a combination of embedded and surface-mounted sensors was designed based on the research team's previous experience and the results from the previous Phase I research activities. This system was configured so that the data could be used to study and report on the condition and behavior of the Viking Road Bridge, with a specific interest in the effectiveness of the thermal isolation barrier at minimizing temperature differences/gradients. These data were compared against one another and also evaluated over the complete duration of the project. In addition to the long-term monitoring, the research team conducted bridge inspections (primarily focused on the deck) every six months for the duration of the project with the intent of identifying and documenting deck cracking, if any.

Task 4: Analytic study on the thermally induced effect on the wide bridge. An analytical model of the Viking Road Bridge was developed. The details of the analytical model were similar to those prepared for the Phase I research. The model was calibrated using the field collected data. Further, the effect of the thermal isolation barrier on aiding the bridge deck end cracking issue was investigated on the validated model.

Task 5: Preparation of draft final report. The data from the field instrumentation and analytical modeling was analyzed to study the effectiveness of the thermal isolation barrier. The research team prepared the draft final report documenting all tasks completed, conclusions, and recommendations with respect to wide bridge design details.

1.5 Report Overview

- Chapter 2 summarizes and presents the key findings from the Phase I research and documents the review of a series of current studies on bridge thermal fields.
- Chapter 3 documents the key information for the design and construction of the Viking Road Bridge over IA 58, along with its instrumentation, monitoring, and inspection results.
- Chapter 4 covers the FE model development and validation of the model for the analytical study of the bridge, along with the analytical study results for the efficacy of its thermal isolation barrier.
- Chapter 5 presents the summary and conclusions from this research effort.

CHAPTER 2. LITERATURE REVIEW

The Phase I literature search was conducted with a focus on the findings and experience from other state DOTs, NCHRP project reports, the Transportation Research Record journal, and TRB proceedings to identify current work related to improving the performance of wide bridges. The majority of this task had been achieved via the previous study, although a new search of relevant material was conducted to include any recent developments on the topic.

In this report, the findings from the Phase I work was reviewed, and the key findings are summarized and presented in Section 2.1. A series of current studies on bridge thermal fields was reviewed and is documented in Section 2.2.

2.1 Phase I IHRB Project TR-661

IHRB project TR-661 (Phares et al. 2015) was completed to determine the maximum width of a continuous deck that can be used without negatively impacting performance. It consisted of a combination of tasks including bridge inspections, FE modelling, short-term bridge testing, long-term bridge testing, and the development of recommendations.

The field-testing component was conducted on Bridge #605220 located near Waterloo and was completed to provide general behavioral information on a wide bridge and provide data for the calibration of an analytical model that would be used in other portions of the research. The bridge had an integral abutment and 12 pre-stressed concrete girders supporting an approximately 80 ft wide concrete deck. The bridge had experienced heavy deck cracking near both ends but was otherwise in very good condition.

For the short-term testing, 60 strain transducers were installed on the bridge and monitored as a heavily loaded truck crossed the bridge at various transverse positions. The collected data were analyzed and revealed that, overall, the bridge was very stiff longitudinally and transversely. The long-term testing focused on studying the behavior of the bridge during temperature changes. Long-term behavior information was collected via a suite of strain, temperature, and displacement sensors installed on the girders, deck, and one abutment.

The analytical bridge model that was created consisted of discrete idealizations of the deck, girders, diaphragms, abutments, and pier caps. To initially calibrate the model, the live load response data were used to minimize percent errors between analysis results and field measurements. Principal calibration at this point focused on material and gross geometric properties.

Next, the accuracy of the model was compared to the long-term collected data and it was deemed that the model (and general modeling approach) was sufficiently accurate to be used in further parametric studies. Using the validated modeling approach, a parametric study was conducted to investigate the effect of bridge width on crack development and other parameters, such as bridge skew, girder spacing, abutment type, pier type, and the number of spans.

The results indicated that increasing the bridge width increased the maximum strain in the deck by 20–30 microstrain. However, this increase was not significant compared to the magnitude of the deck strain values, because, even for the narrowest bridge width, the maximum strain exceeded the cracking strain. It was also found that the maximum tensile strain in the deck of the integral abutment bridge model was two to three times higher than the strain in the stub abutment model. The study of the other factors—pier type, girder type, girder spacing, and number of spans—showed that these factors had little effect on the strain in the deck near the abutment.

One of the primary conclusions of this work was that the development of cracking in bridge decks seems less dependent on the total width of the deck and more dependent on restraint of the abutment to temperature changes and, in particular, temperature gradients. The following recommendations were made:

- If deck cracking is a major concern in certain situations, the use of a stub abutment is recommended.
- To obtain a better understanding of bridge deck behavior, a bridge with both integral and stub abutments is recommended to be monitored for long-term behavior and performance.
- Based on the FEM results, an effective solution to reduce cracking in the deck might be to place a thermal isolation barrier between the soil and back side of the abutment.
- Vertical expansion joints in the abutment do theoretically help to reduce the strain in the deck and control the maximum strain location in the deck. However, implementation presents several problems.

2.2 Bridge Thermal Fields

A literature search was conducted with a focus from the Phase I study on the bridge thermal fields and their impact on bridge structural behavior. The results indicated that many research studies have been conducted to investigate the thermal effect on various types of bridge structures. For example, Xu et al. (2010) monitored the temperature effect on a long suspension bridge, Cai et al. (2012) investigated the effects of temperature variations on the in-plane stability of steel arch bridges, Rodriguez et al. (2014) studied the temperature effects on a box-girder integral-abutment bridge, and Yang et al. (2018) monitored the thermal effect on tower displacements of cable-stayed bridges. However, these research studies contribute minimum applicable information to this project due to the differences in the structure types.

With respect to a precast, prestressed, concrete girder bridge with integral abutments, except for the Phase I research (Phares et al. 2015), very limited research was found.

Kim and Laman (2010) developed the numerical modeling methodologies based on an extensive field monitoring program over four integral abutment bridges to predict the long-term bridge response. The research focused on the irreversible soil/structure interaction and time-dependent effects of the superstructure in the case of prestressed concrete girders. Both field-measured and numerical responses indicated that soil/structure interaction and time-dependent effects significantly influence long-term integral abutment bridge behavior.

Lee (2012) conducted experimental and analytical studies on a prestressed concrete girder bridge to determine the transverse and vertical temperature gradients in prestressed concrete girders. The aim of this work was to aid engineers in predicting the thermal behavior of prestressed girders during construction.

Rodriguez (2012) monitored the temperature response of an integral abutment bridge for nearly one year using a dense array of thermocouples throughout the depth of the bridge deck and over the height of the girders. Changes in concrete temperatures were recorded resulting in maximum and minimum average values in addition to temperature gradients.

However, both of these studies were conducted with a focus on the thermal distribution and the structural response on the deck-girder composite action; none of the studies investigated the impact from an integral abutment.

CHAPTER 3. BRIDGE DESIGN, CONSTRUCTION, AND EVALUATION

The bridge on Viking Road over IA 58 was selected to deploy the findings from Phase I research The bridge was designed with a width of 228 ft, which is much greater than the 60 ft width requiring the use of longitudinal joints per the Iowa Bridge Design Manual (Iowa DOT 2012). The bridge deck has no longitudinal joints, but based on the previous research results, a thermal isolation barrier was used to separate the integral abutment and backfill soils with the intention of reducing deck end cracking.

The research team followed and documented the design, construction, and performance of the bridge with a specific focus on the efficacy of the crack mitigation efforts. Monitoring was conducted for nearly two years to investigate the bridge temperature distribution and study the thermal effect on the bridge deck behavior. Following the completion of the bridge construction, multiple bridge inspections were conducted to observe the deck for any crack development.

This chapter documents the key information related to the research interest during the bridge design and construction completion in Section 3.1 and 3.2, respectively. Section 3.3 and 3.4 record the bridge instrumentation work and monitoring results, respectively. The field inspection results are presented in Section 3.5.

3.1 Bridge Design

This bridge was a single span bridge measuring 115 ft long by 228 ft wide on a 0-degree skew. Figure 1 shows the completed bridge looking south along IA 58.

Figure 1. Viking Road Bridge over IA 58

Figure 2 shows an aerial image of the completed bridge with the bridge plan view overlaid for clarity.

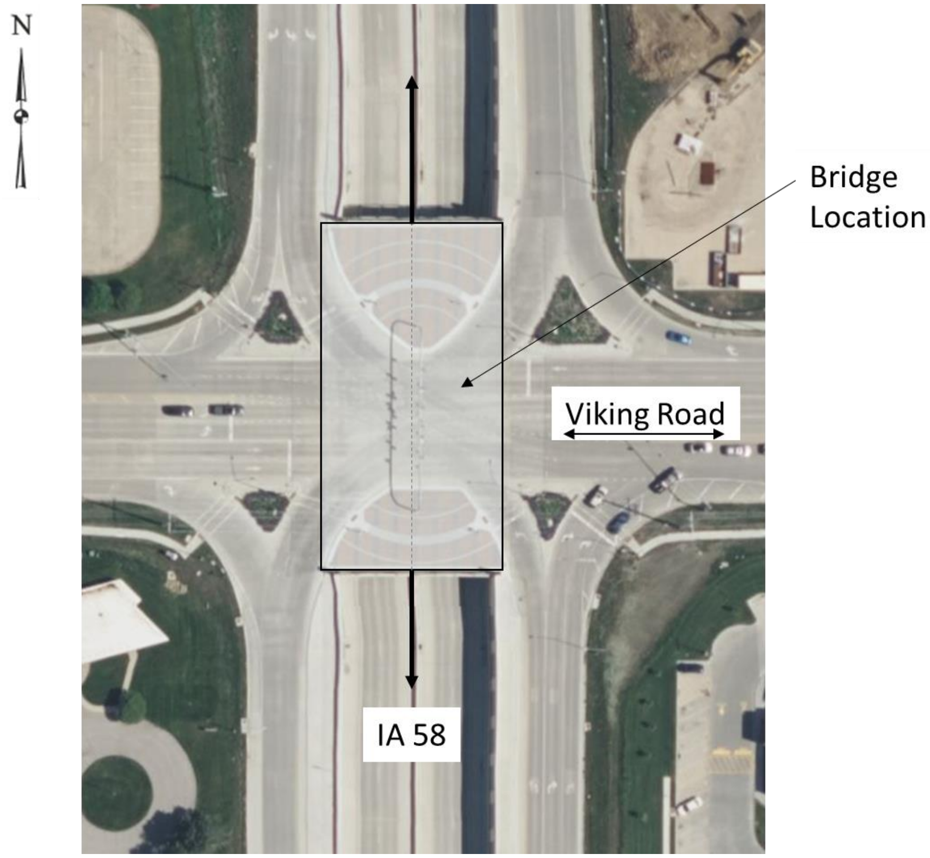


Figure 2. Viking Road Bridge over IA 58

Figure 3 shows the cross-section view looking east for the north half of the bridge superstructure.

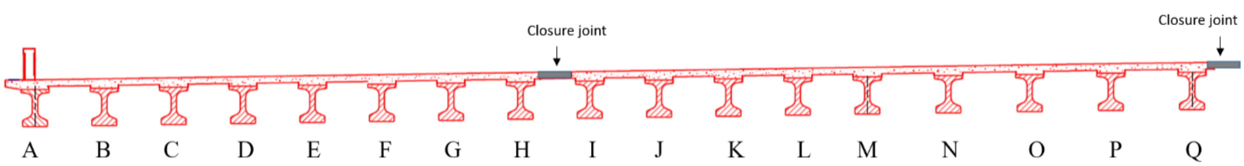


Figure 3. Bridge cross-section view

The bridge consisted of 31 precast, pre-stressed, concrete girders. Girders are alphabetically labeled beginning with A for the northern-most girder in Figure 3.

Based on the recommendation from the previous research (Phares et al. 2015), this bridge design employed an expanded polystyrene (EPS) block behind the integral abutments to create thermal isolation from the adjacent backfill soils. Figure 4 shows the cross-section view of this isolation barrier.

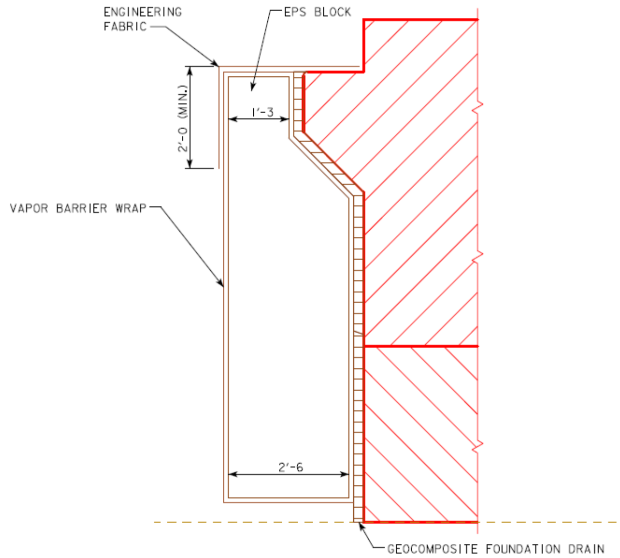


Figure 4. Cross-section view of thermal isolation barrier

In general, the isolation barrier was 2.5 ft thick. However, the thickness was reduced to 1.25 ft to accommodate the paving notch near the top of the abutment.

During the design of the bridge, the research team worked closely with the bridge design team to finalize the design of the thermal isolation barrier. To provide details and clear guidelines for the construction engineers, the following (partial) notes were included in the plans for the EPS block:

> *A THEMAL ISOLATION PAD SYSTEM SHALL BE INSTALLED AT THE BACK OF THE FACE OF EACH ABUTMENT AS DETAILED ON THIS SHEET. IT SHALL CONSIST OF A GEOCOMPOSITE FOUNDATION DRAIN WITH FILTER FABIRC AND AN EXPANDED POLYSTYRENE (EPS) INSULATION BLOCK WITH VAPOR BARRIER. SEE TABLES FOR APPROVED MATERIALS.*
>
> *THE INTENT OF THE THERMAL ISOLATION PAD IS TO INSULATE THE ABUTMENT FROM THE ADJACENT SOIL TO PROMOTE A UNIFORM TEMPERATURE BETWEEN THE DECK AND THE ABUTMENT FOOTING. IT WILL BE PART OF A RESEARCH PROJECT BY IOWA STATE UNIVERSITY.*
>
> *THE INSULATION SHALL BE A CLOSED CELL, EXPANDED POLYSTYRENE (EPS) MARKETED FOR BELOW-GRADE APPLICATION. THE MINIMUM COMPRESSIVE STRENGTH OF THE MATERIAL SHALL BE 10.9 PSI AT 1% DEFORMATION USING TEST METHOD ASTM D6817.*
>
> *THE INSULATION SHALL HAVE A MINIMUM R-VALUE OF 60 AT 75 DEGREES ACHIEVED BY SINGLE HOMOGENEOUS BLOCK. THE THICKNESS REQUIRED TO ACHIEVE THE MINIMUM R VALUE SHALL BE MAINTAINED AROUND THE PAVING NOTCH.*

3.2 Bridge Construction

During the spring of 2019, the abutment footings were cast and readied for girder placement. The bridge deck and abutment diaphragm placement began in early June 2019. Figure 5 shows the timeline for the schedule of bridge construction, field monitoring, and inspections.

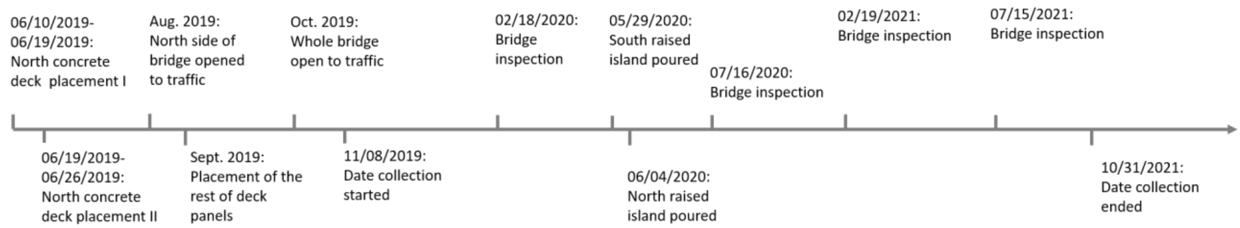


Figure 5. Timeline of field construction and monitoring

The bridge deck concrete was placed in four separate pours excluding the three closure pours. The first pour was between June 10 and June 19, 2019, and the second was between June 19 and June 26, 2019. The remaining pours were completed in September. See Figure 6 for the location of the first two deck pours and the area of monitoring.

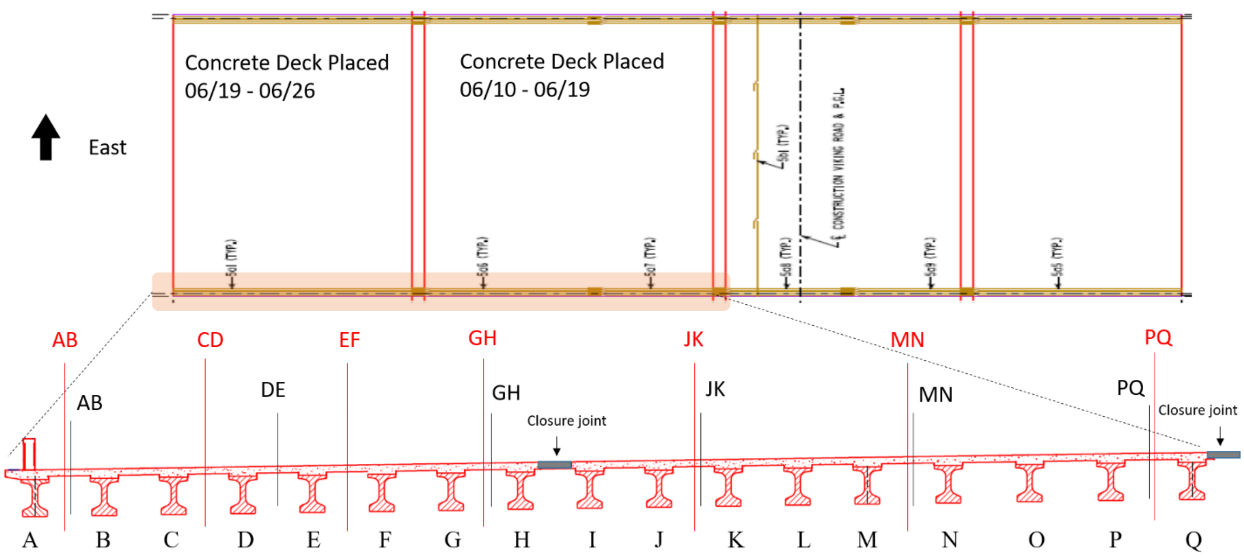


Figure 6. Deck placement and cross-section of monitored area of bridge

Three construction joints were formed in the deck to facilitate construction. The deck reinforcement was continuous through the joints, which were completed using a closure pour between the adjacent deck placements. Note that these construction joints are not the longitudinal expansion joints commonly used in past projects to provide the expansion and contraction relief for wide bridges.

Since the bridge was designed with an integral abutment, the abutment diaphragm concrete was placed together with the deck concrete. After the placement of the bridge deck and abutment diaphragm concrete, the thermal isolation barrier was placed along the back side of both abutments, as shown in Figure 7 and Figure 8.

Figure 7. Preparing for placement of EPS isolation barrier

Figure 8. Installation of EPS isolation barrier

Figure 9 shows the bridge deck top surface (near the abutment) after the bridge opened to traffic.

Figure 9. Deck end at West abutment

The north side of the bridge deck construction was completed in June 2019, and it opened to traffic in the middle of August 2019. The second half (south) deck was poured in September and the whole bridge was opened to traffic in October 2019. In June 2020, two half-ellipse raised islands were placed on the bridge deck, one on the north side and one on the south side. Figure 10 shows the map for the raised island on the north side of the bridge deck.

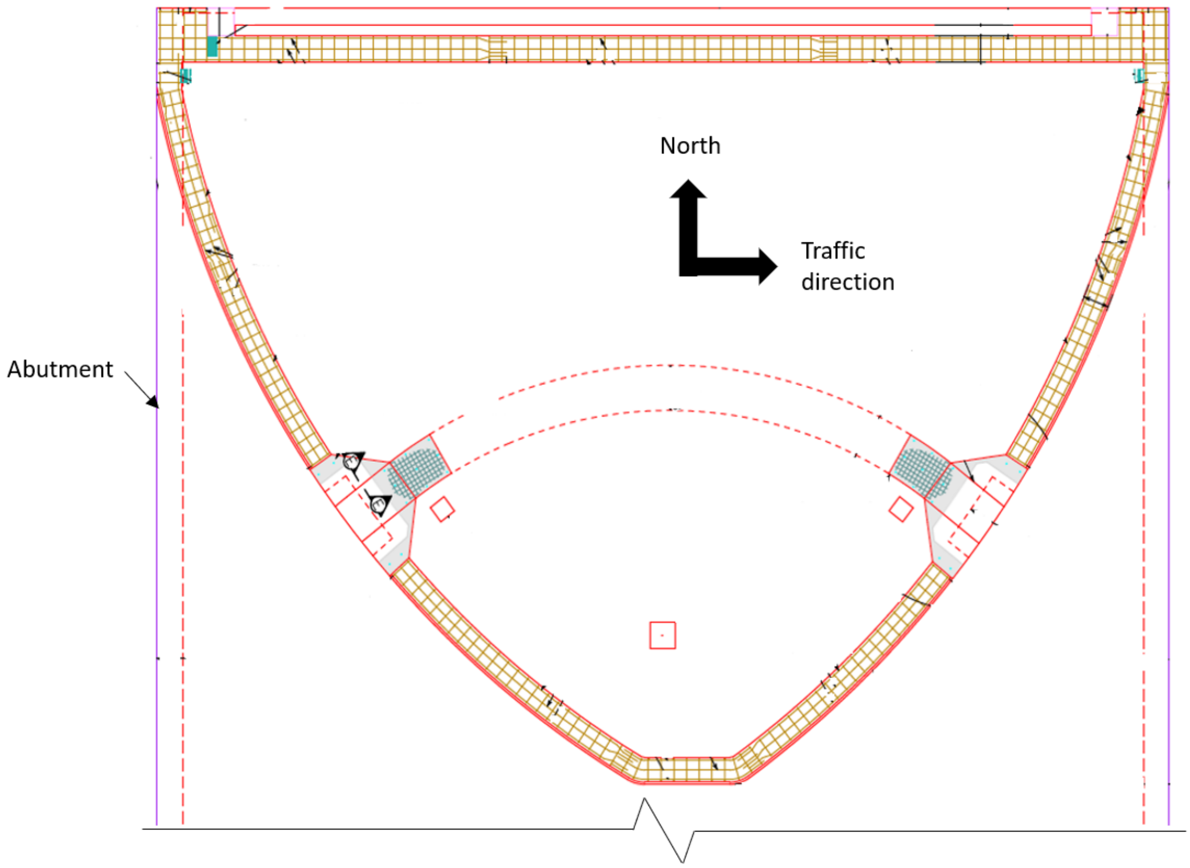


Figure 10. Raised island on the north side of the bridge top

Figure 11 shows the raised island and the rail on the bridge deck after construction completion.

a) Raised island

b) Rail

Figure 11. Raised island and decorative rails

Although these raised islands do not likely add any appreciable structural capacity, their existence likely affects the temperature field and dead load distribution. Fortunately, data collection began immediately after the initial phase of superstructure construction and the structural behavior during the construction of the raised islands was recorded.

3.3 Instrumentation Design

The instrumentation plan was designed to study and report on the condition and behavior of the Viking Road Bridge with a specific interest in determining the effectiveness of the thermal isolation barrier at minimizing temperature differences/gradients between the abutment and bridge deck. The installed instrumentation included both embedded and externally mounted sensors and were generally similar to that used during the Phase I research.

Two types of sensors were used during the field monitoring: thermistors and vibrating wire strain gauges (VWSGs). In total, 96 Geokon 3810 thermistors and 6 Geokon 4000 VWSGs were installed at six unique sections, generally located at the midpoint between two adjacent girders. The sections were labeled according to the adjacent girder labels (i.e., Section AB was located between girders A and B). Sections AB, DE, GH, JK, MN, and PQ are shown in the previous Figure 6. At each section, 16 thermistors and one VWSG were installed. All of the gauges were installed in a single plane at the middle of each girder bay. The strain gauges were placed in the transverse deck position. Figure 12 shows the gauge locations in one instrumented section.

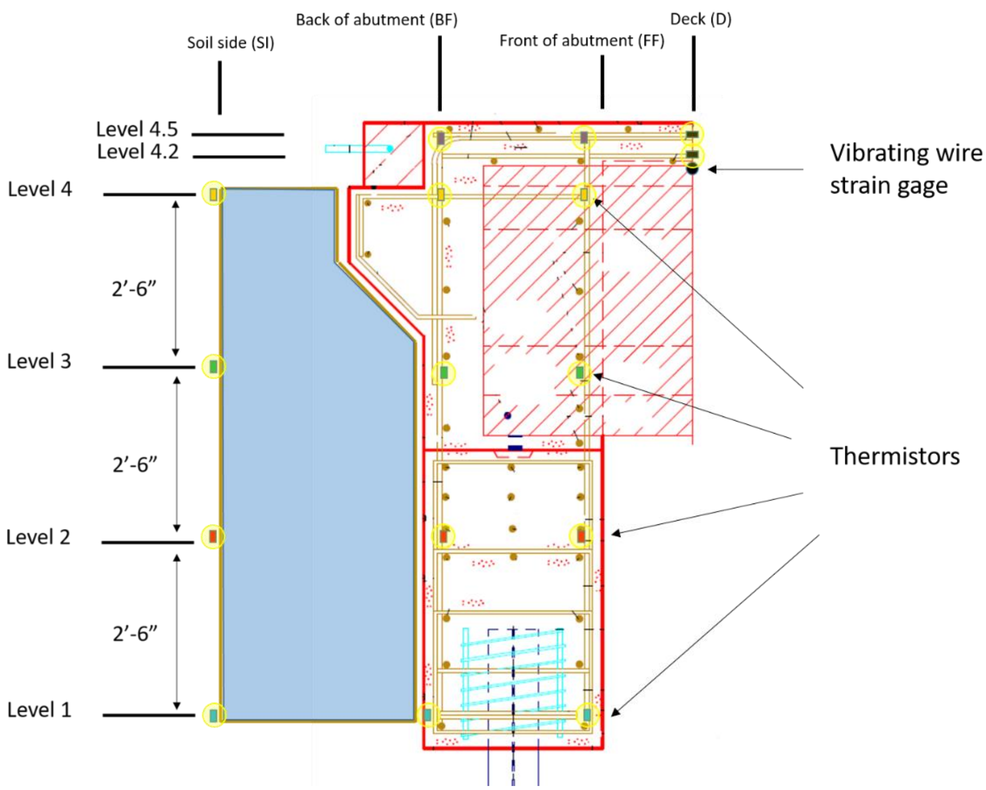


Figure 12. Instrumentation plan for each section

To gain an understanding on the effectiveness of the thermal isolation barrier on the temperature field, thermistors were utilized and embedded into the abutment and near the deck end. In general, all the gauges were placed into one of six levels in the vertical direction (from bottom to top: Level 1, Level 2, Level 3, Level 4, Level 4.2, and Level 4.5) and four sections in the bridge longitudinal direction: soil interface (SI), back face of abutment (BF), front face of abutment (FF), and deck (D). Level 4.2 is at the same level as the bottom reinforcing steel bar in the deck, and Level 4.5 is at the same level as the top reinforcing steel bar in the deck. The deck (D) section was located 7.5 ft from the front face of the abutment.

Digital images were captured during the installation of instrumentation. The research team followed the bridge construction schedule and completed the physical instrumentation along with bridge deck construction. Figure 13 shows the prestressed, precast girders placed in the field.

Figure 13. Prestressed girder placement

Figure 14 shows the wire arrangement along the end of the bridge deck.

Figure 14. Thermistor wires placed in abutment formwork

Figure 15 shows one embedded thermistor in the abutment.

Figure 15. Thermistor placement in deck and at back face of abutment

Figure 16 shows one embedded thermistor in the deck.

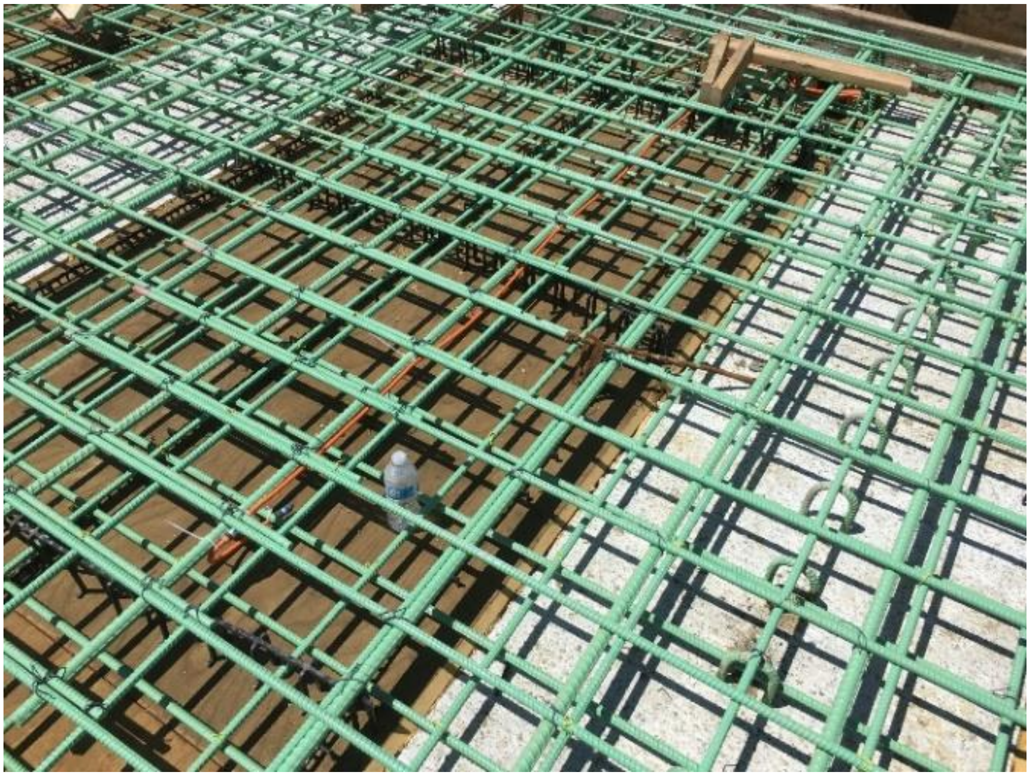


Figure 16. Thermistor placement along deck reinforcement

Figure 17 and Figure 18 show the abutment formwork and the wire alignment for the thermistor in the abutment.

Figure 17. Abutment formwork

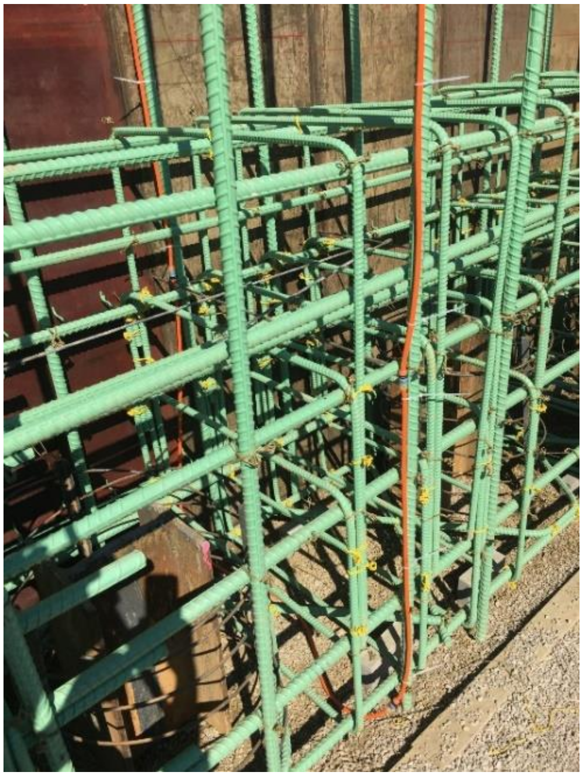


Figure 18. Thermistor placement at front face of abutment

Similar to the instrumentation plan used in the Phase I research work, one VWSG was attached to the deck (D) at the bottom surface of the deck to measure the strain development in the bridge transverse direction as shown in the previous Figure 12. Figure 19 shows the attached VWSG at the bottom of the bridge deck.

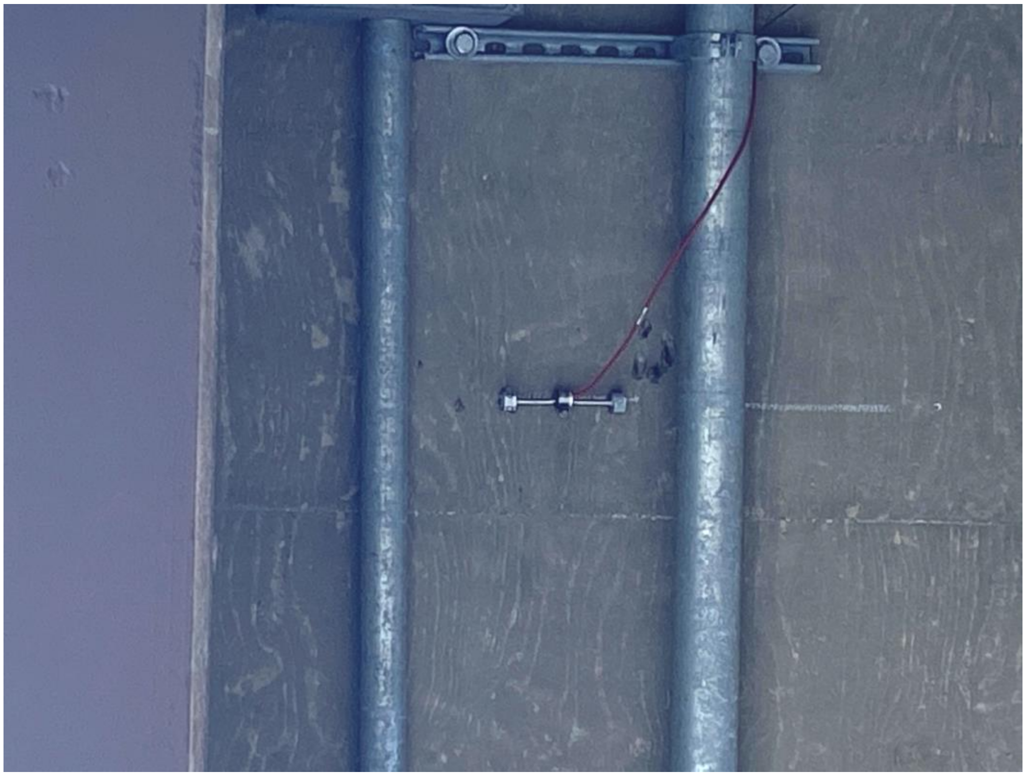


Figure 19. Vibrating wire strain gauge on the deck bottom

Based on the results from the Phase I research work, VWSGs at this location will provide sufficient data for the evaluation of the bridge deck end behavior subject to thermal loading.

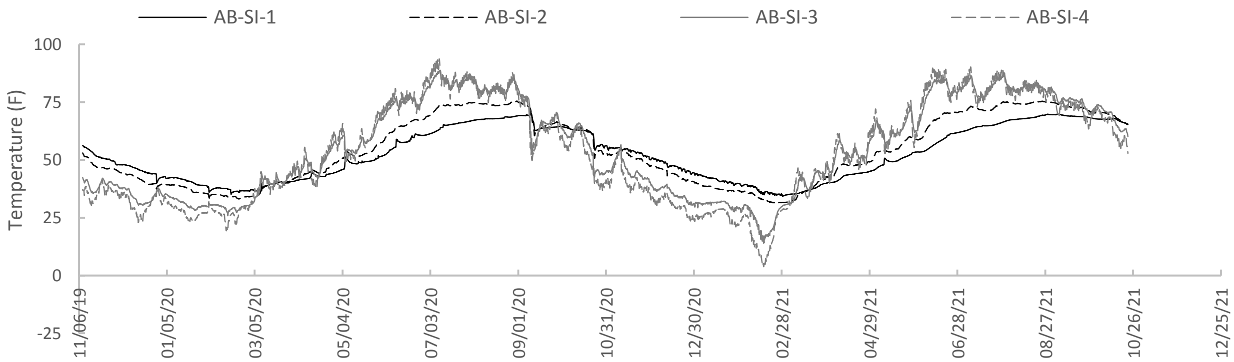
The temperature data collected during the field monitoring were also used as thermal loading during the analytical work covered in Chapter 4. In addition, the strain data were utilized to validate the analytical model.

3.4 Monitoring Results

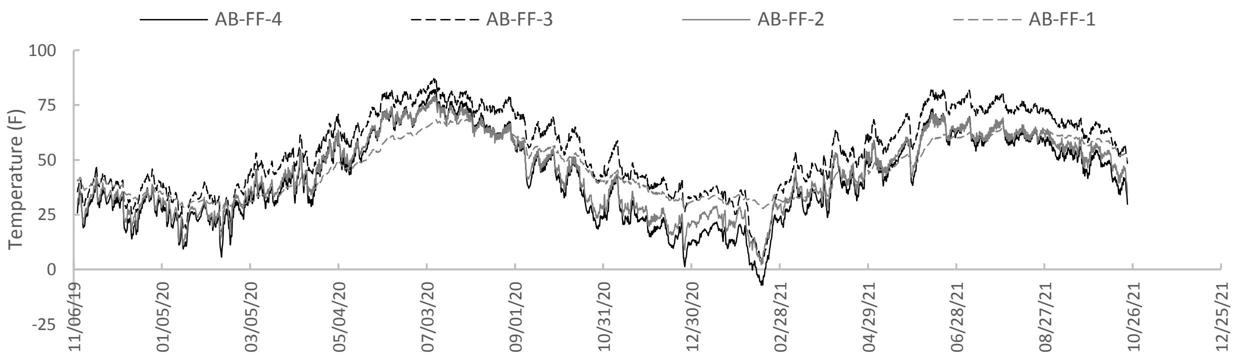
In this section, the data collected during the monitoring period are analyzed and discussed. The key findings are presented.

3.4.1 Thermistors data

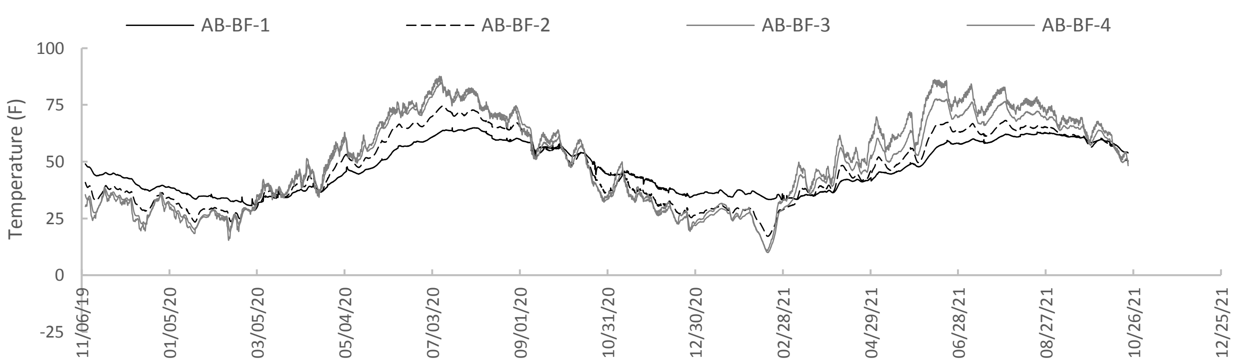
Figure 20 through Figure 25 show the temperature data collected from each of the six instrumented bays.



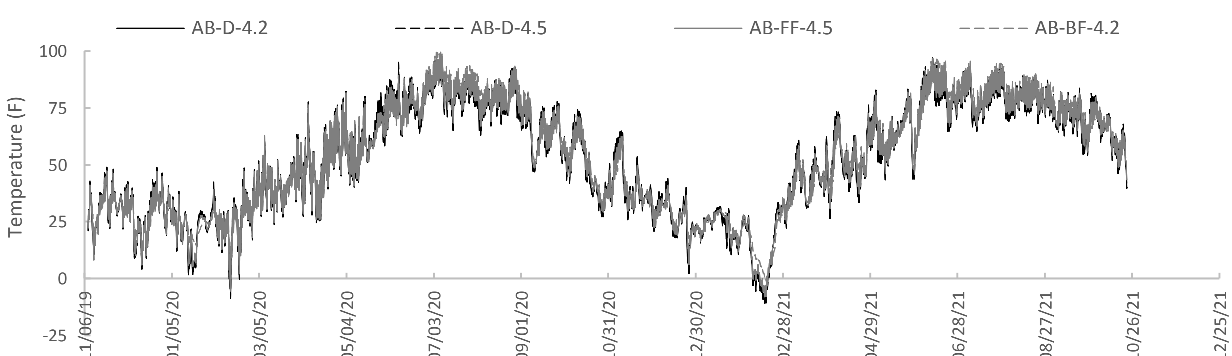
a) Soil side temperature



b) Abutment back side temperature

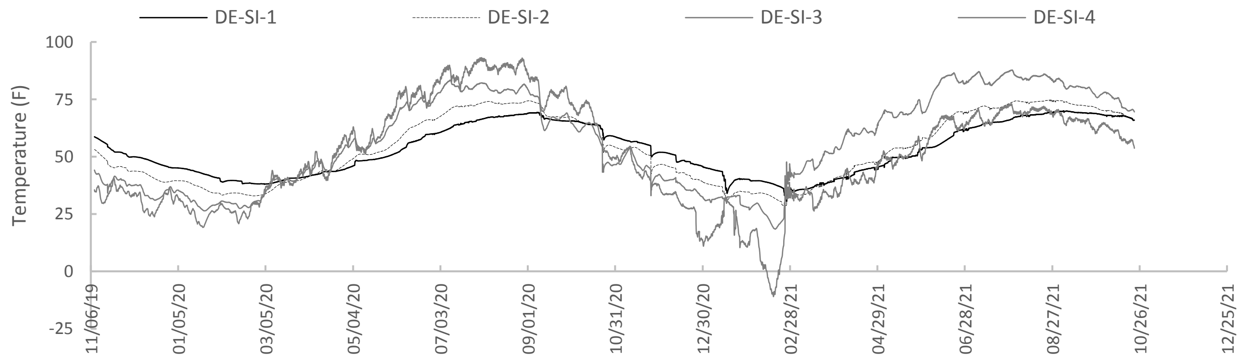


c) Abutment front face temperature

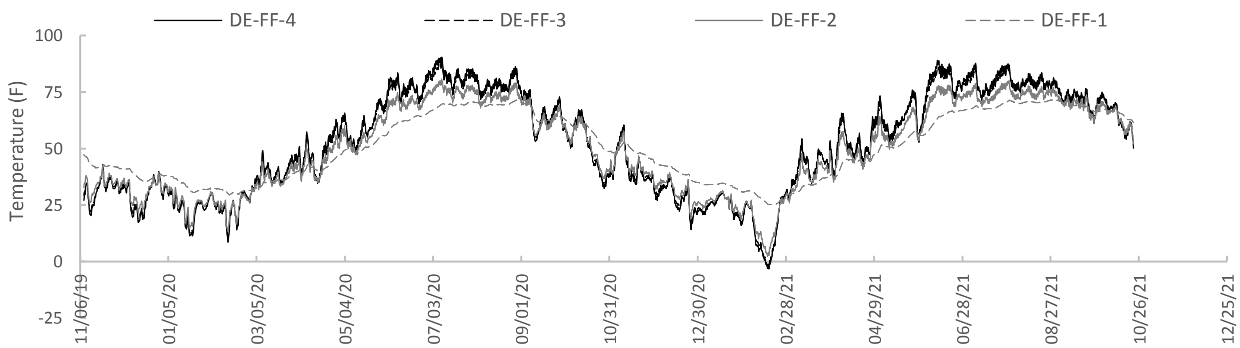


d) Deck and abutment top temperature

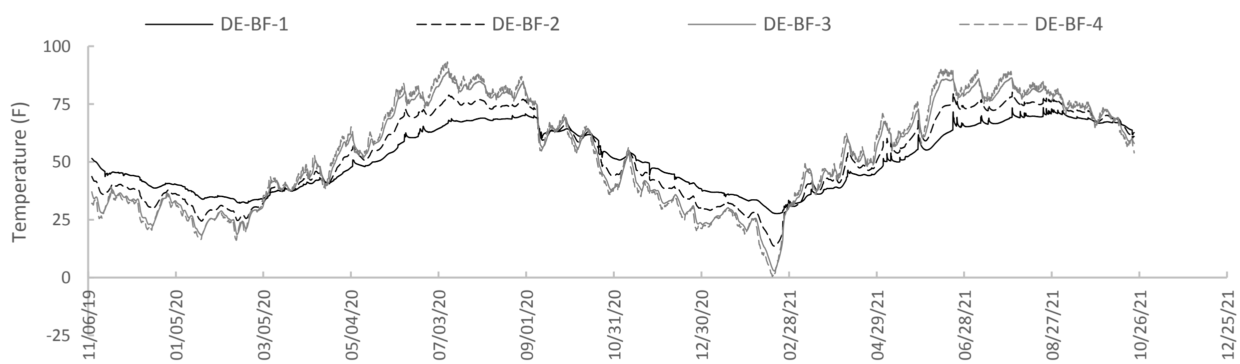
Figure 20. Temperature data from Bay AB



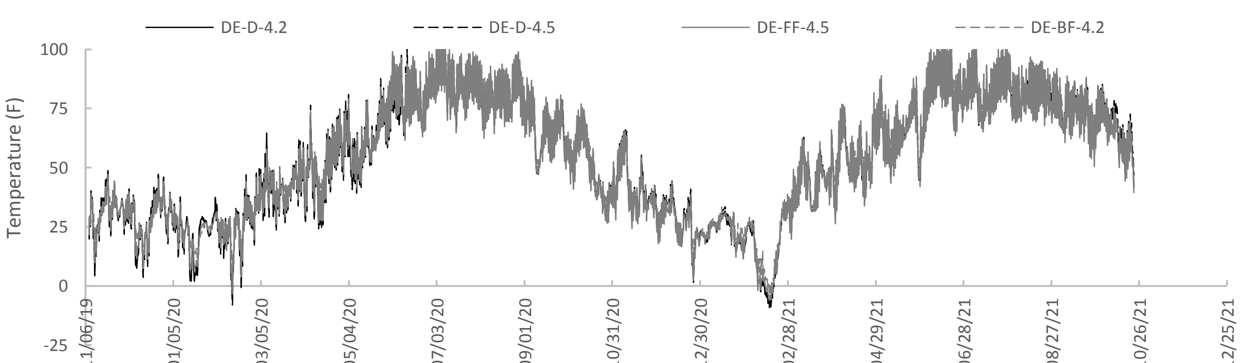
a) Soil side temperature



b) Abutment back side temperature

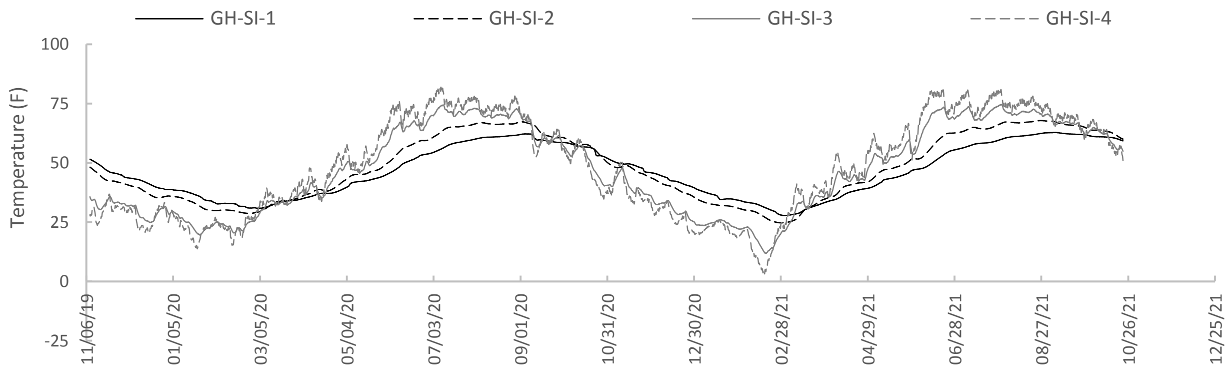


c) Abutment front face temperature

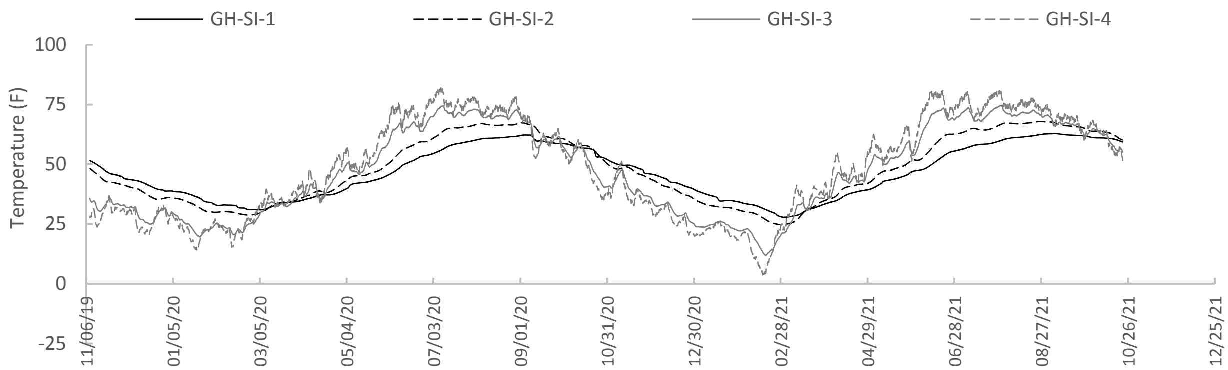


d) Deck and abutment top temperature

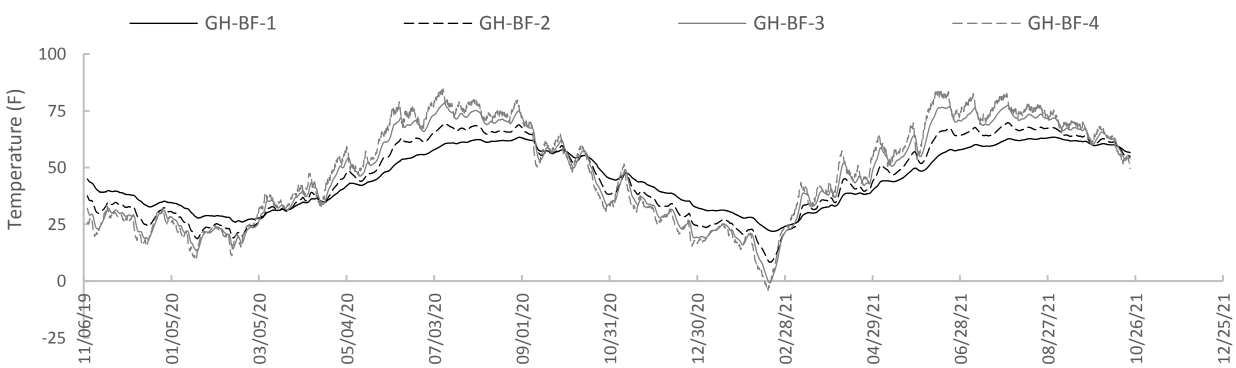
Figure 21. Temperature data from Bay DE



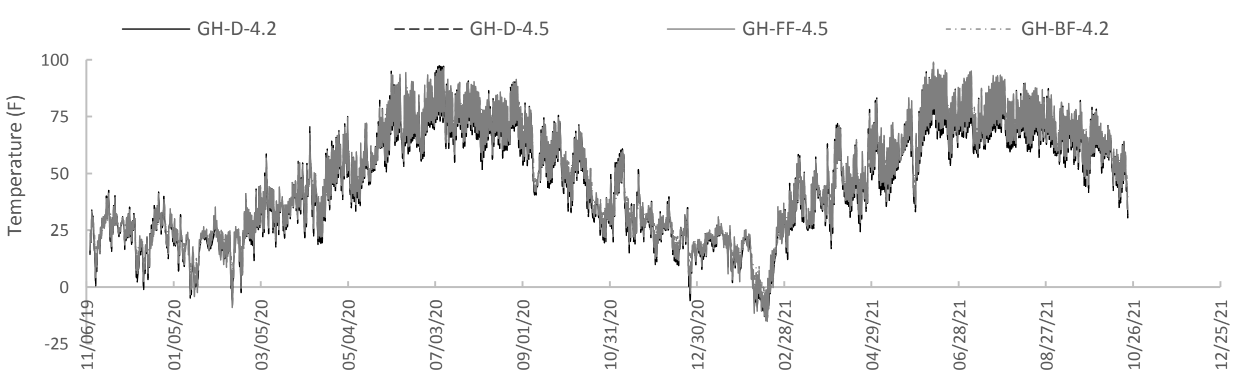
a) Soil side temperature



b) Abutment back side temperature

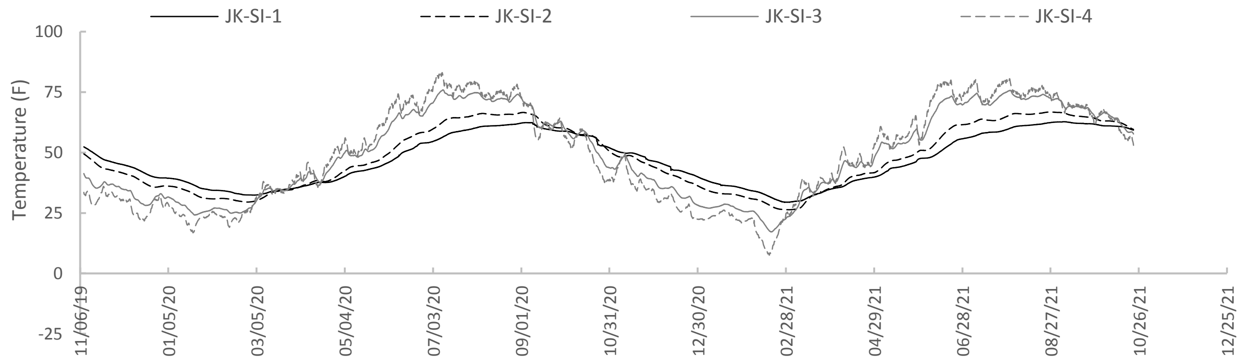


c) Abutment front face temperature

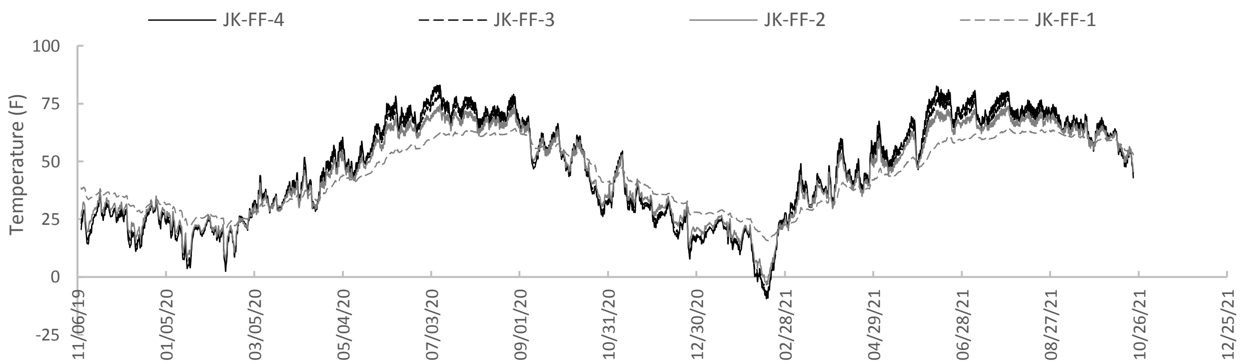


d) Deck and abutment top temperature

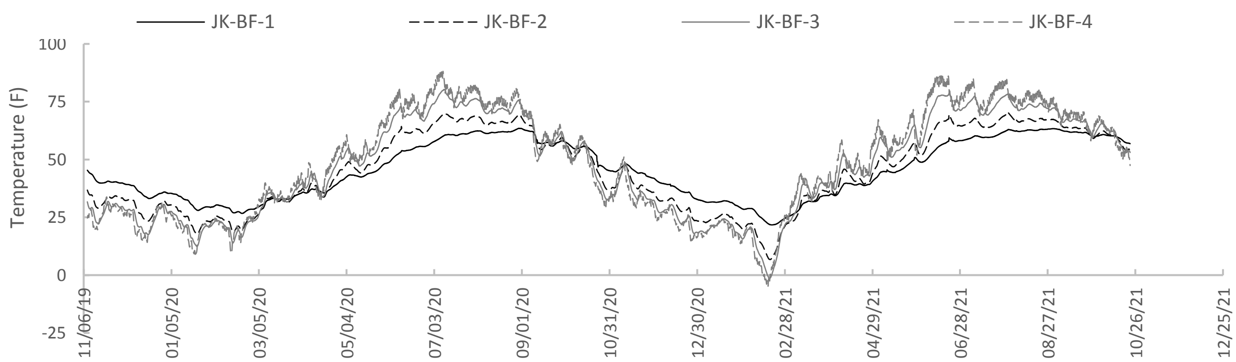
Figure 22. Temperature data from Bay GH



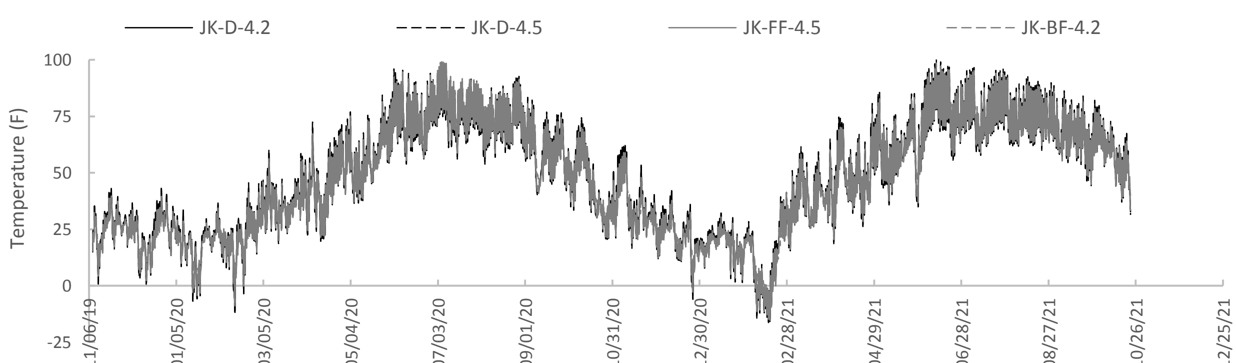
a) Soil side temperature



b) Abutment back side temperature

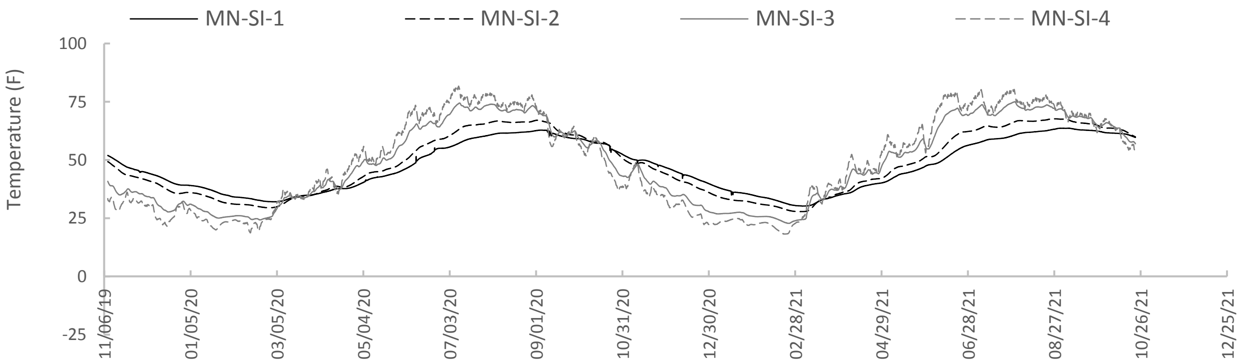


c) Abutment front face temperature

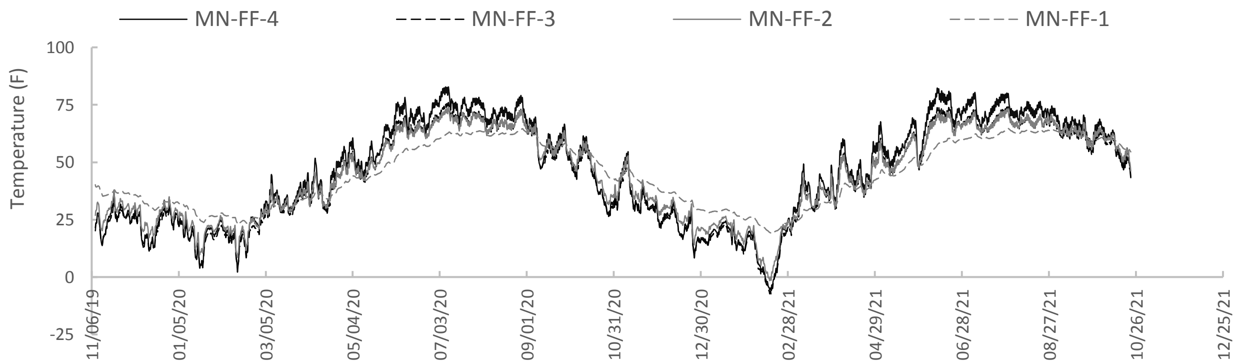


d) Deck and abutment top temperature

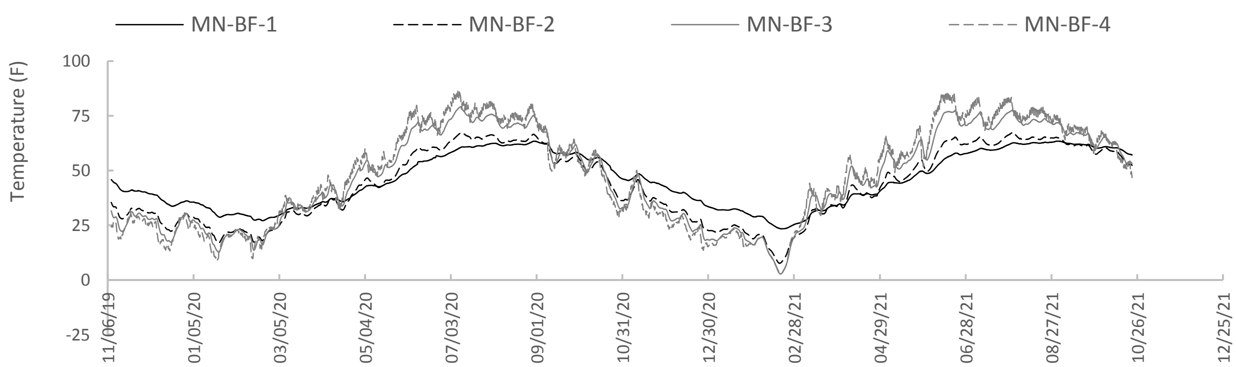
Figure 23. Temperature data from Bay JK



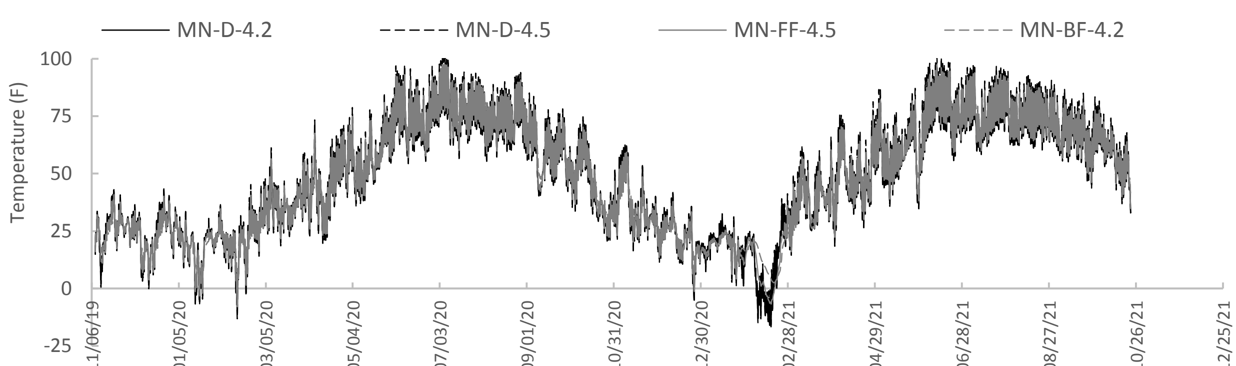
a) Soil side temperature



b) Abutment back side temperature

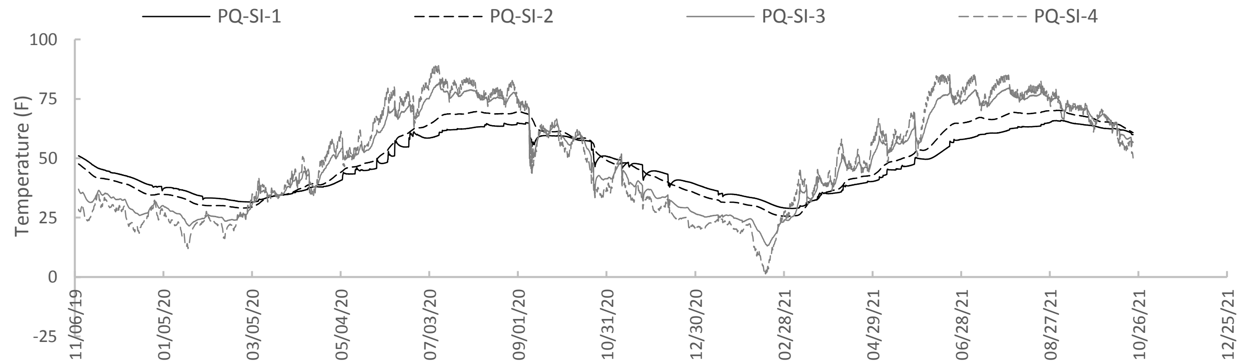


c) Abutment front face temperature

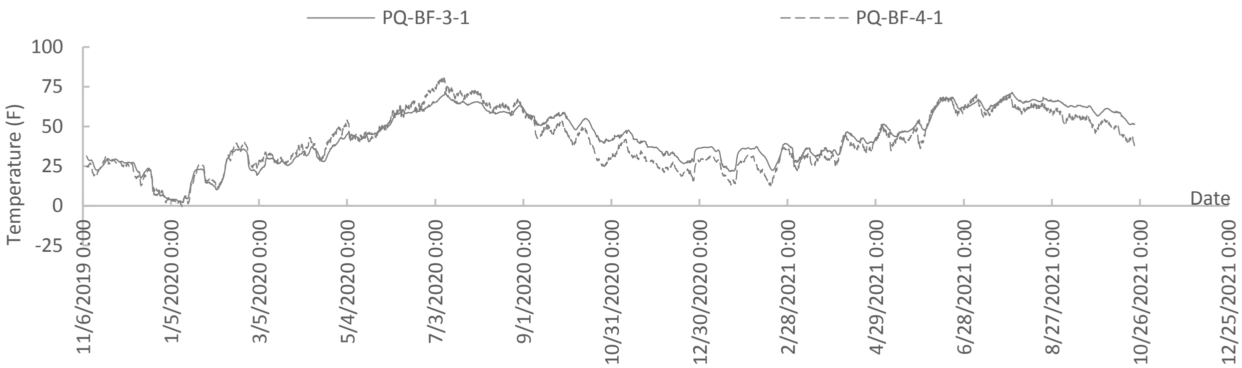


d) Deck and abutment top temperature

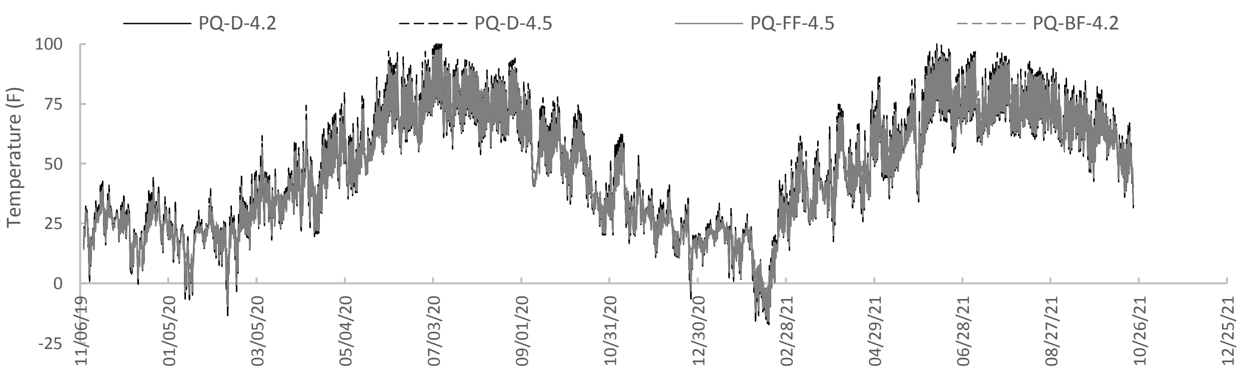
Figure 24. Temperature data from Bay MN



a) Soil side temperature



b) Abutment front face temperature



c) Deck and abutment top temperature

Figure 25. Temperature data from Bay PQ

In these figures, the data were labeled in a way to identify the gauge instrumentation section, vertical position, and longitudinal location. For example, AB-SI-1 indicates the gauge is in Bay AB, at the soil interface of the isolation barrier, and at Level 1 in the vertical direction. (See the previous Figure 6 for the instrumented bays and the previous Figure 12 for the level number and section name.)

Note that one of the thermistor strings in Bay PQ, which included the thermistors PQ-FF-1, PQ-FF-2, PQ-FF-3, PQ-FF-4, PQ-BF-1, and PQ-BF-2, did not produce any data; the string was likely damaged during the completion of abutment construction.

Looking at these figures, it is evident that the temperature trends with the seasonal variation in temperatures. Furthermore, the sensitivity and fluctuation of the temperature changes on a daily basis is greater with respect to the vertical position. Thermistors more near the top of the abutment and those within the bridge deck showed greater sensitivity to the ambient temperature changes and solar heating of the deck. Thermistors lower in the abutment were naturally less sensitive due to shading of the overall thermal mass.

Figure 26 compares the temperature data collected at Level 1 and 4 on the back face of the abutment from all six instrumented bays.

The data in this figure and at other locations indicated that, for most of the time, the temperature distribution along the abutment in the bridge transverse direction was very consistent with the difference being less than 5°F. During very cold days or periods with abrupt ambient temperature changes, like that on February 4, 2021, this difference increased to about 10°F.

Figure 27 compares the temperature data from Level 1 and 4 in Bay MN; other bays had similar trends.

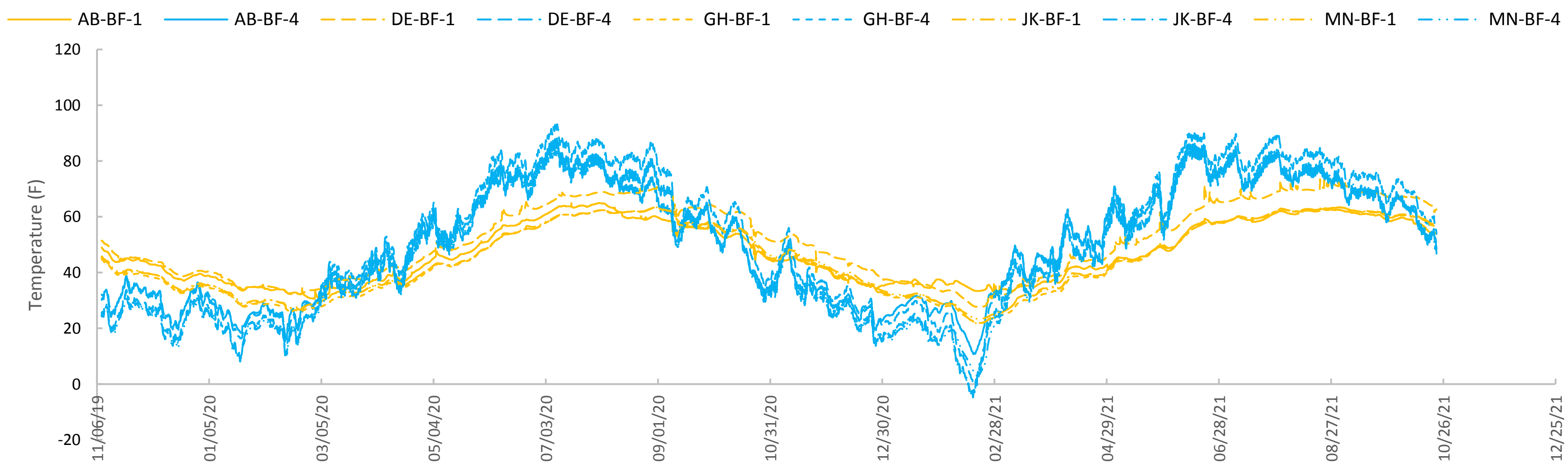


Figure 26. Temperature distribution over bridge transverse direction at abutment back face at Level 1 and Level 4

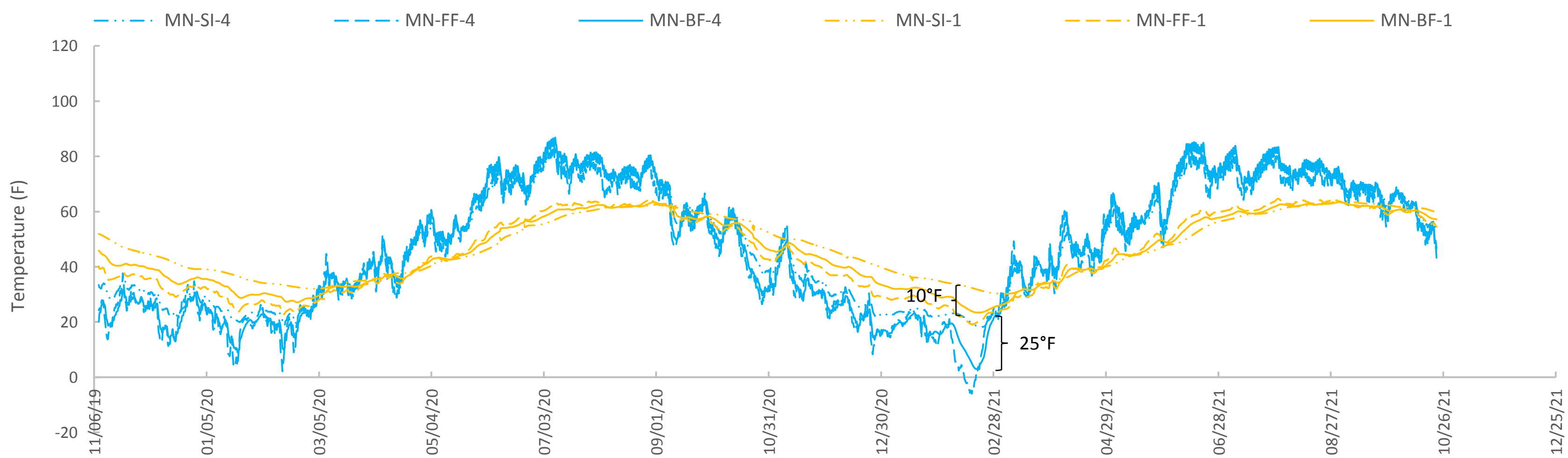


Figure 27. Temperature distribution at Level 1 and Level 4 at bay MN

It was found that the temperature level at which the higher and lower temperatures were measured reversed in early March and the middle of September of each year, which is consistent with the rise and fall of the average ambient temperatures. For example, during the period from March to the middle of September, the temperature at Level 4 (top of abutment) was higher than Level 1 (bottom of abutment), while, during the period from late September to March of the following year, the peak temperature location reversed.

In addition, a vertical temperature gradient was observed when comparing all three sections from front to back of the abutment and thermal isolation barrier: FF, BF, and SI. For example, on the soil side (SI) of the isolation barrier, the maximum vertical temperature gradient from Level 1 to 4 was about 25°F during the winter. However, the maximum vertical temperature gradient on the back face of the abutment (BF) was about 10°F.

When comparing the FF temperatures to the BF and SI temperatures, it was evident that the thermal isolation barrier likely reduced the temperature gradient from the front to back of the abutment. The temperature differences were consistently 10 to 15°F greater when comparing the FF to SI temperatures. The data also showed that the temperature gradient within the abutment was more consistently controlled at the lower level (Level 1) than at the upper level (Level 4).

Figure 28 presents the plots for the temperature data collected from the back and front of the abutment.

It was found that the temperatures at the BF and FF at each level were very close with the differences less than 10°F. With the thermal isolation barrier, the deck and abutment temperatures were very close even when there was a sudden ambient temperature drop. The thermal isolation barrier was effective in reducing the temperature gradient through the abutment thickness.

Figure 29 presents the comparison of the temperature at Level 4 to the temperature in the deck and at the top of the abutment (Levels 4.2 and 4.5) for Bay AB.

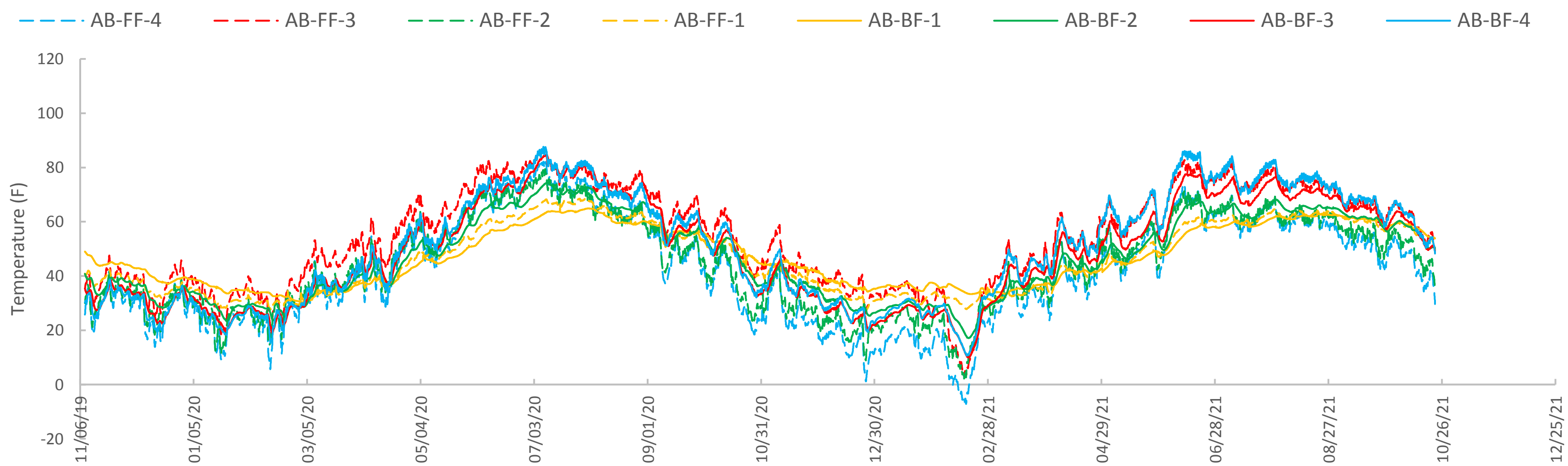


Figure 28. Temperature distribution at abutment back face and front face

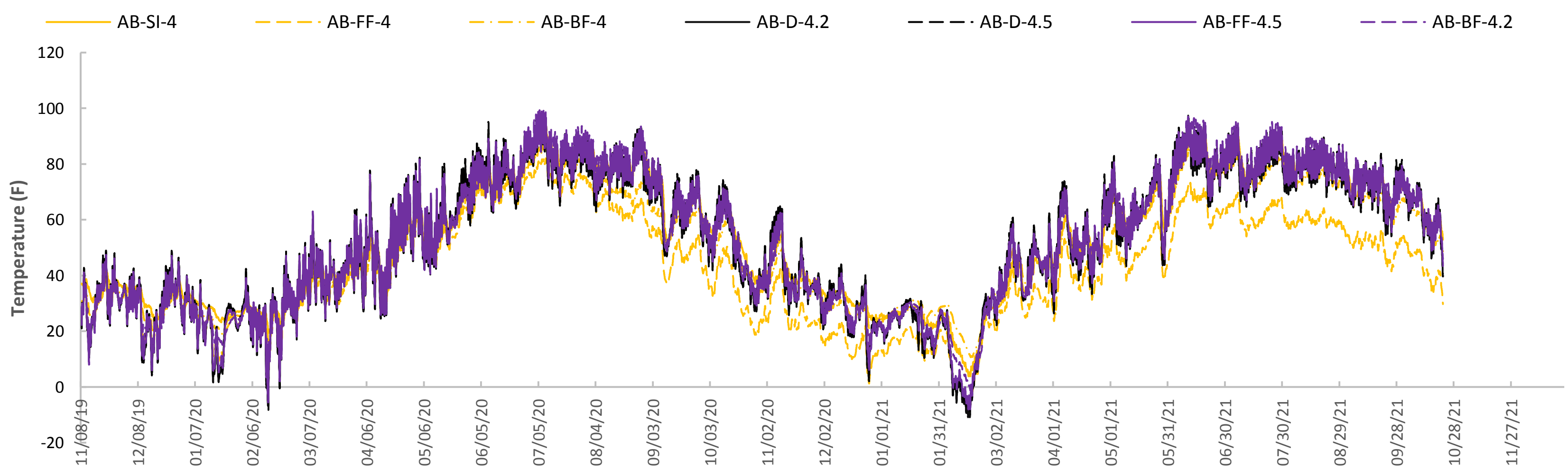


Figure 29. Temperature distribution near the top of abutment and at the deck at Bay AB

The results generally show a greater sensitivity to ambient temperatures and solar heating for those thermistors at the very top of the abutment and in the deck compared to those at Level 4. It was also evident that the raised island affected the temperature trend when constructed. The temperature at Level 4 trended similarly, but generally at a lower temperature than before the island was placed.

3.4.2 VWSG data

Strain and temperature data were collected at the bottom of the deck in each of the girder bays indicated in the previous Figure 6. It should be noted that the placement of the raised island was completed early in June 2020, approximately 8 months after the bridge was opened to traffic. Figure 30 shows the relative locations of the VWSGs in Bays AB and DE and the raised island.

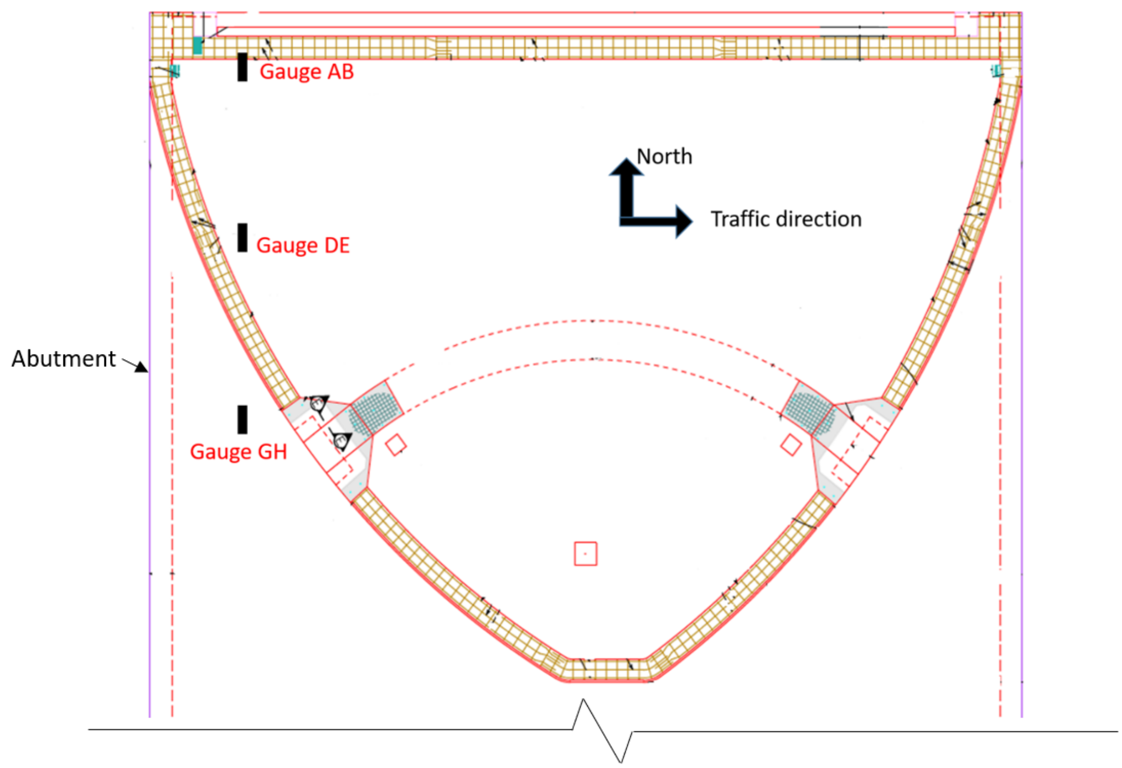
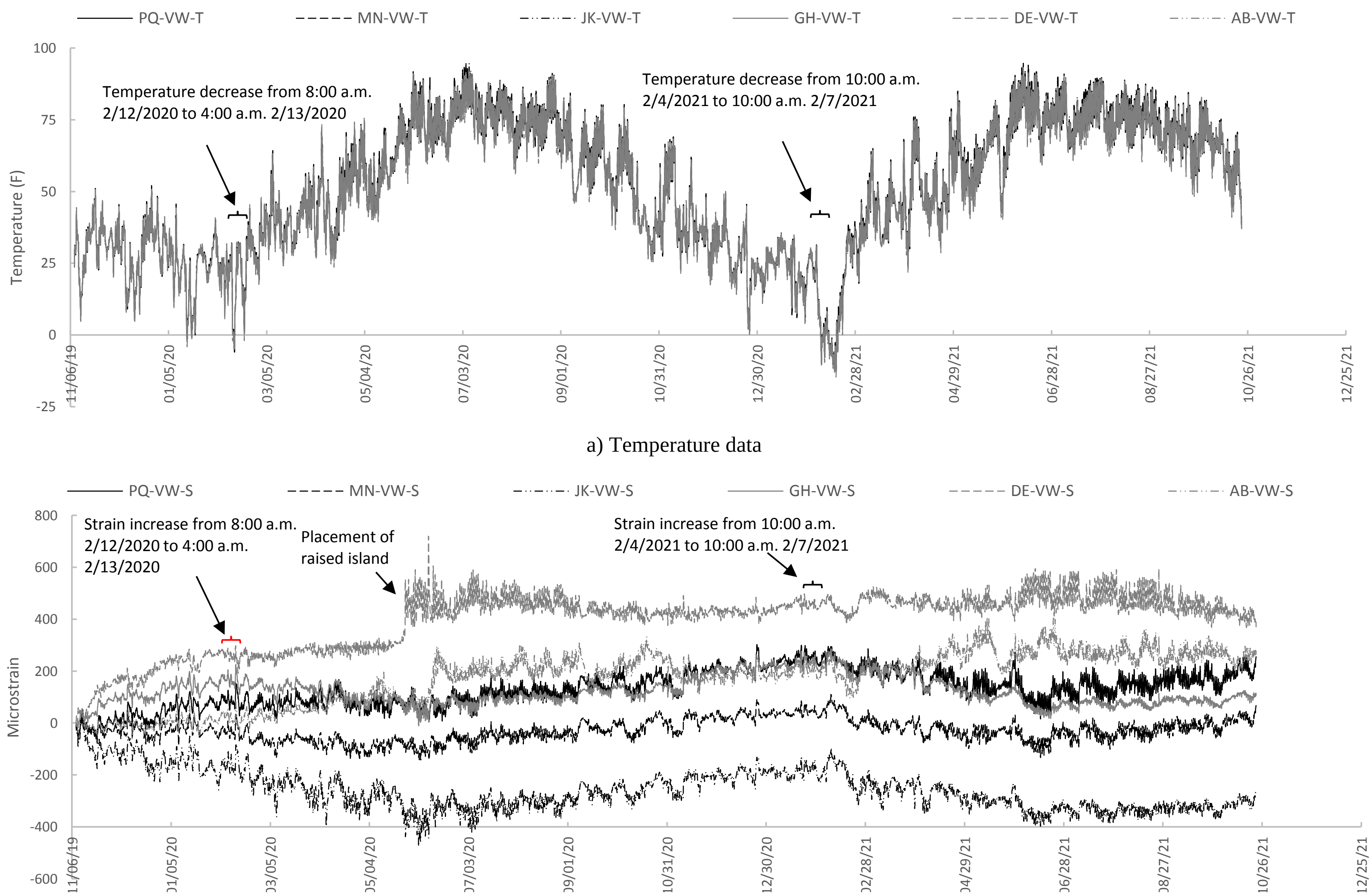


Figure 30. Deck strain gauge position relative to the raised island

Figure 31-a shows the temperature data collected from the VWSGs attached on the bottom of the deck.



a) Temperature data

b) Strain data

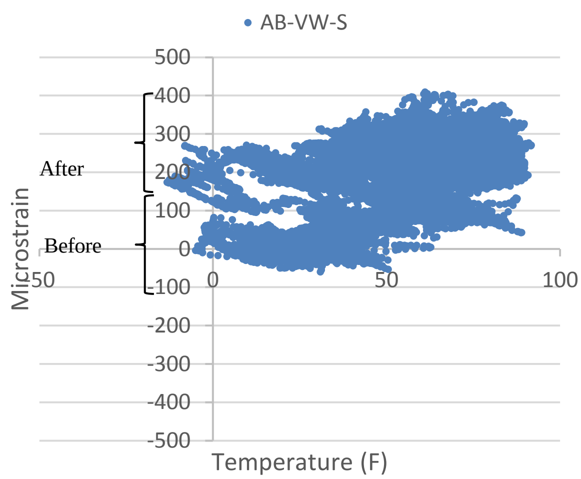
Figure 31. VWSG data

Compared to the data from the other bays after the island placement, it was found that larger daily temperature variations occurred at the deck bottom in Bay AB and Bay DE. This indicated that the raised island affected the temperature distribution on the deck.

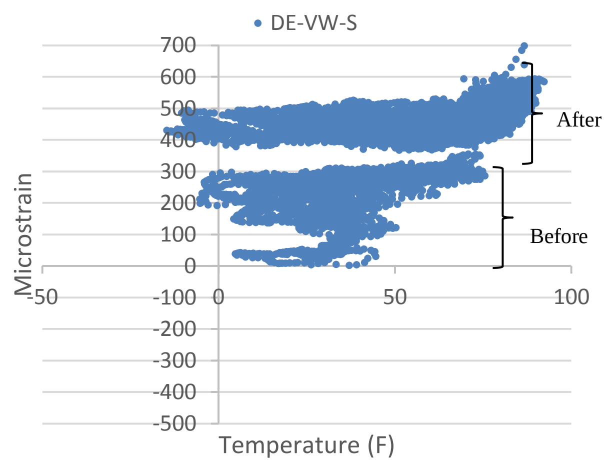
Figure 31-b shows the strain data collected from all six VWSGs. Although these data have been zeroed at the beginning of the data collection and corrected for the thermal effect, the strain magnitude for some gauges reached to hundreds of microstrain. It should be pointed out that these strains are not completely induced by thermal or live loads; they also include bridge deck concrete shrinkage, creep, etc. The dead load of the raised island was also reflected in the data and significantly increased the strain in Bays AB and DE. A larger daily strain variation existed in Bays AB and DE after placement of the raised island. This phenomenon was significant during the summer months.

Similar to the findings from the Phase I research that the deck end transverse strain increases when the ambient temperature suddenly decreases, such phenomena was observed on the Viking Road Bridge. For example, the temperature decreased during 8:00 a.m. February 12, 2020 to 4:00 a.m. February 13, 2020 and 10:00 a.m. February 4, 2021 to 10:00 a.m. February 7, 2021 (shown in Figure 20 to Figure 25). During both periods, the VWSGs attached near the deck end captured a significant strain increase in the transverse direction.

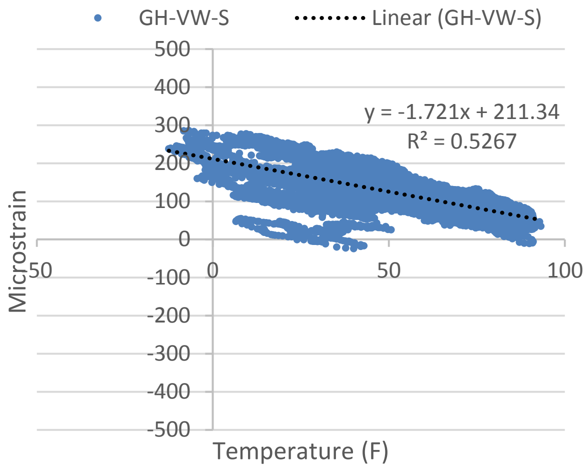
Figure 32-a to-f plot the strain data versus the temperature data collected from each VWSG.



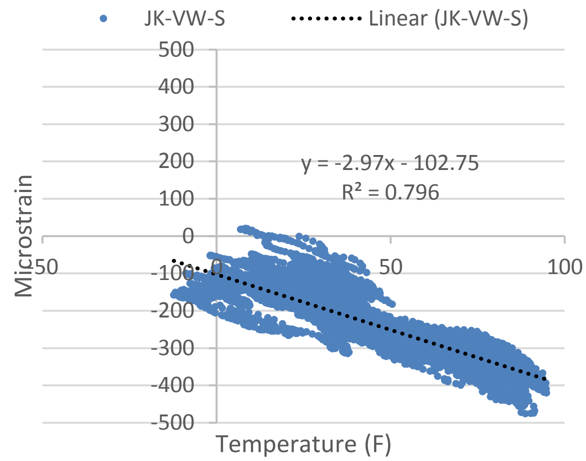
a) Bay AB



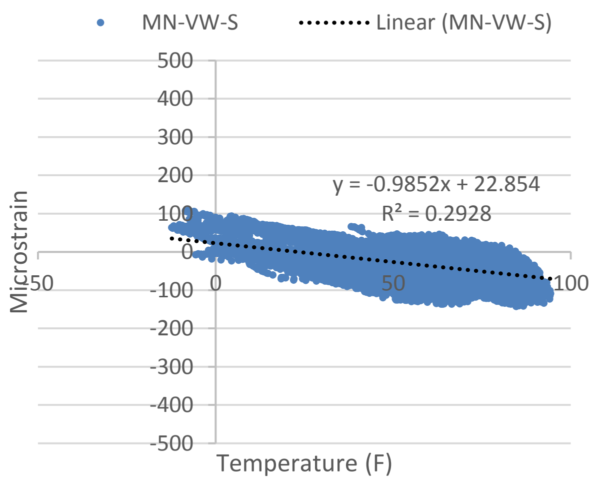
b) Bay DE



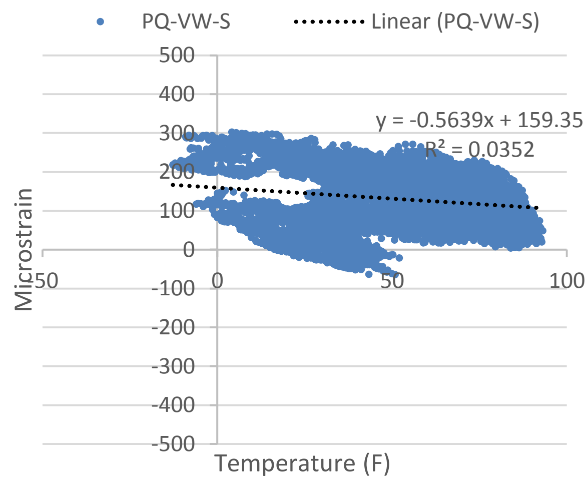
c) Bay GH



d) Bay JK



e) Bay MN



f) Bay PQ

Figure 32. Strain data vs. temperature

The data collected from gauges AB-VW-S and DE-VW-S distributes into two groups as shown in Figure 32-a and -b. This separation is caused by the construction of the raised island. As shown in the previous Figure 30, the raised island was directly over the gauges AB-VW-S and DE-VW-S, and the weight of the raised island induced an increase in the strain reading. Such phenomenon was not observed in the data collected from other strain gauges (Figure 32-c to -f).

With the strain data collected in each of Bays GH, JK, MN, and PQ concentrated with no clear separation, a linear regression was performed to fit the data with least deviation (R^2). The results indicated a negative relation between the temperature and strain data; that is, as the temperature decreased, the strain decreased. By averaging the slopes of the linear regression line in Figure 32-c to -f, it was found that the strain increased 1.56 microstrain when the temperature increased 1°F.

3.5 Field Inspection

After completion of construction, the bridge was regularly visited to complete a visual inspection of the bridge deck. The inspection involved visual observation of the top and bottom of the deck near the abutment locations. The final bridge inspection occurred on May 23, 2022 and, up to this date, no cracks were observed. For nearly three years, the bridge had been subject to vehicular loads and the seasonal effects of temperature.

The inspection results speak well to the positive effects of the isolation barrier behind the abutments. These results support the findings from the Phase I research that development of cracking in bridge decks seems less dependent on the total width of the deck. Images are provided in Figure 33 through Figure 41 showing the visual results from the onsite inspections.

Figure 33. Total bridge width looking north

Figure 34. Deck inspection May 2022 West abutment

Figure 35. Deck inspection May 2022 East abutment

Figure 36. Deck inspection May 2022 Bay AB

Figure 37. Deck inspection May 2022 Bay DE

Figure 38. Deck inspection May 2022 Bay GH

Figure 39. Deck inspection May 2022 Bay JK

Figure 40. Deck inspection May 2022 Bay MN

Figure 41. Deck inspection May 2022 Bay PQ

While on site, it was noted that the condition of the flanking sidewalks, barrier rail, and raised island at the north and south of the bridge experienced varying levels of cracking, which required repair. It is presumed that the barrier rail and sidewalk lengths leading up to the bridge were such that their expansion pushed them directly against the bridge, and the compressive forces created were large enough to result in cracking. Images are provided in Figure 42 through Figure 46 showing some of the damaged areas.

Figure 42. Spalling of rail at northeast corner

Figure 43. Raised island spalling

Figure 44. Raised island spalling and repair

Figure 45. Raised island repair at southeast corner

Figure 46. Raised island repair

CHAPTER 4. ANALYTICAL STUDY

The objective of performing the analytical study was to gain a comprehensive understanding of how much the isolation barrier affects the deck end behavior. The analytical study was performed utilizing commercial FE software, ANSYS APDL.

The analytical model of the Viking Road Bridge was developed with details similar to those prepared for the Phase I research. The model was calibrated using the field-collected strain data. Further, the effect of the thermal isolation barrier on the prevention of the bridge deck end cracking issue was investigated on the validated model.

4.1 FE Model Development

The FE model was created for the superstructure including the bridge deck, precast concrete girders, and the abutment. Figure 47 shows a general overview of the model.

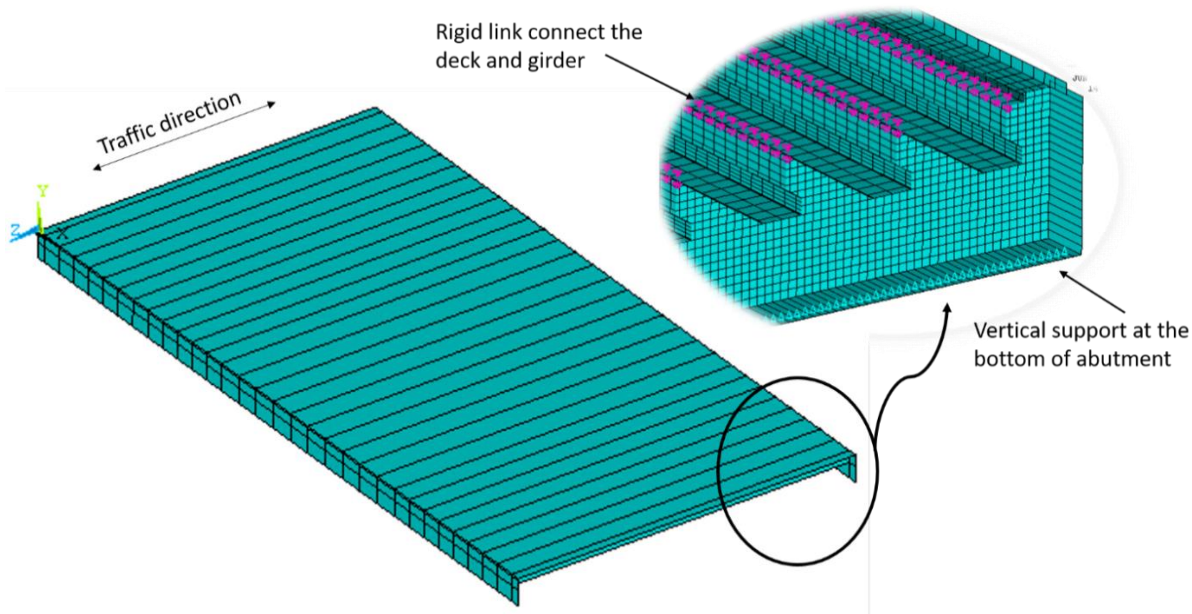


Figure 47. Finite element bridge model

The FE model was developed utilizing the modeling approach used in the Phase I research. The shell element was used to model the bridge abutment, deck, and girder web, and the beam element was used to model the top and bottom flange of the girder. Table 1 lists the modeling details.

Table 1. Finite element model details

Bridge component	Element type	Strength (Plan)	Young's modulus (ksi)
Deck	Shell	4 ksi	3,750(Ex); 3,605 (Ey); 3,800 (Ez)
Abutment	Shell	4 ksi	3,605
Girder – top flange	Beam	9 ksi	5,407
Girder – web	Shell	9 ksi	5,407
Girder – bottom flange	Beam	9 ksi	5,407

Based on the original design plans for the bridge, the specified compressive strength (f_c') for the pre-stressed girder was 9 ksi and, for the concrete in the other bridge components, 4 ksi. The Young's modulus for concrete was calculated using $57{,}000\sqrt{f_c'}$ (ACI 2011) yielding the Young's modulus of 5,407 ksi for the pre-stressed girder and 3,605 ksi for the other concrete components. Poisson's ratio for all the concrete members was taken as 0.2.

The steel reinforcement in the concrete deck was also considered by smearing them into the concrete. To simulate this orthotropic behavior of the bridge, an effective thermal expansion coefficient (α_{eff}) and an effective Young's modulus (E_{eff}) were determined using equation (1) and equation (2) (Liu et al. 2016):

$$\boldsymbol{E_{eff} = \frac{A_c E_c + A_s E_s}{A_c + A_s}} \quad \textbf{(1)}$$

$$\boldsymbol{\alpha_{eff} = \frac{A_c E_c \alpha_c + A_s E_s \alpha_s}{A_c E_c + A_s E_s}} \quad \textbf{(2)}$$

where:

E_{eff} = effective linear elastic modulus of combined steel and concrete
α_{eff} = effective thermal expansion coefficient of combined steel and concrete
A_c = area of concrete
A_s = area of steel
E_c = linear elastic modulus of concrete
E_s = linear elastic modulus of steel
α_c = thermal expansion coefficient of concrete
α_s = thermal expansion coefficient of steel

Similar to the Phase I work, the shear connection between the girders and the deck was simulated with a short beam element having a very high stiffness. For the piles under the abutment, the bending stiffness of the pile was relatively small compared to that of the other structural elements. So, the rotation stiffness from those piles was ignored.

For the same reason, the translation resistance from the pile in the transverse and longitudinal directions of the bridge was also ignored. Hence, only the vertical support was provided at the bottom of each abutment.

4.2 Model Validation

The results from the Phase I work indicated that the deck end transverse strain experienced an increase when the ambient temperature suddenly decreased. The same phenomena were observed on the Viking Road Bridge. For example, the ambient temperature drastically decreased during the period of 8:00 a.m. February 12, 2020 to 4:00 a.m. February 13, 2020 and during the period of 10:00 a.m. February 4, 2021 to 10:00 a.m. February 7, 2021 (shown in the previous Figure 31). During both periods, the VWSGs attached near the deck end captured a significant strain increase in the transverse direction (previous Figure 31).

In order to validate that the bridge model can accurately simulate the deck end behavior when subjected to the temperature loading, the temperature change from 10:00 a.m. February 4, 2021 to 10:00 a.m. February 7, 2021 was used and applied to the FE model. The strain data collected during this period were used and compared to the analytical results.

As a result of the number of thermistors installed for field monitoring, a comprehensive measurement of the temperatures throughout the abutment and the deck end were successfully obtained. Figure 48 plots the temperature distribution at 10:00 a.m. February 4, 2021 and 10:00 a.m. February 7, 2021.

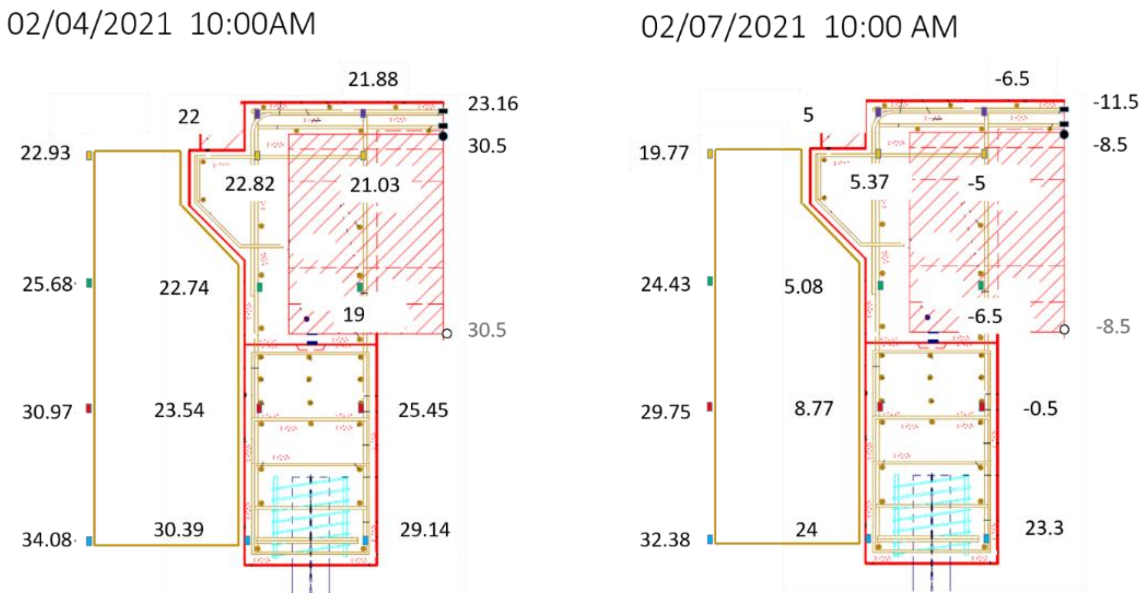


Figure 48. Temperature distribution at 10:00 a.m. February 4, 2021 and 10:00 a.m. February 7, 2021

The temperature at the bottom of the girder flange was estimated to be the same as the deck bottom temperature. This estimation is valid since the temperature gradient on the girder is not likely significant at 10:00 a.m. The temperature between the measurement points was calculated by interpolation. The temperature change over this period was calculated by subtracting the data on 10:00 a.m. February 4, 2021 by the data on 10:00 a.m. February 7, 2021 and applying it to the FE model.

This temperature loading allows simulation of the following: (1) the temperature gradient through the thickness of the abutment, (2) the temperature gradient in the vertical direction of the abutment, (3) the temperature gradient in the deck longitudinal direction, and (4) the temperature gradient in the deck vertical direction. Based on the findings from the field monitoring that temperature distribution in the bridge transverse direction was less than 5°F, a constant temperature over the transverse direction of the bridge was assumed.

Figure 49 compares the field-collected strain change over the period of 10:00 a.m. February 4, 2021 to 10:00 a.m. February 7, 2021 (field monitoring) to the results output from the analytical model (FE Model 1).

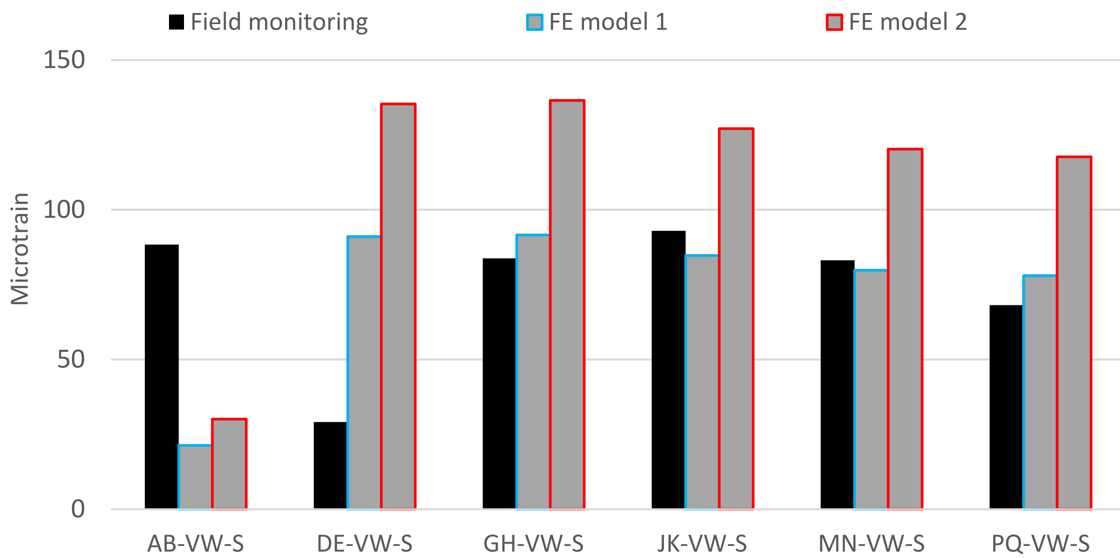


Figure 49. Strain results from Model 1 and Model 2

In general, the results from the analytical model showed an agreement with the field monitoring data for the VWSGs in Bays DE, GH, JK, MN, and PQ (see previous Figure 12 for the instrumentation location). A difference between the analytical and field results existed in Bays AB and DE, but this is believed to be a local effect induced by the raised island on top of this bridge, which was not included in the FE model. Since the raised island is not a structural component and few bridges have an island, the differences in Bays AB and DE were ignored and the model was accepted as valid.

A detailed observation of the FE model results indicated that the maximum strain on the deck occurred at the bottom surface. Figure 50 shows the first principal strain contour plot of the calibrated model.

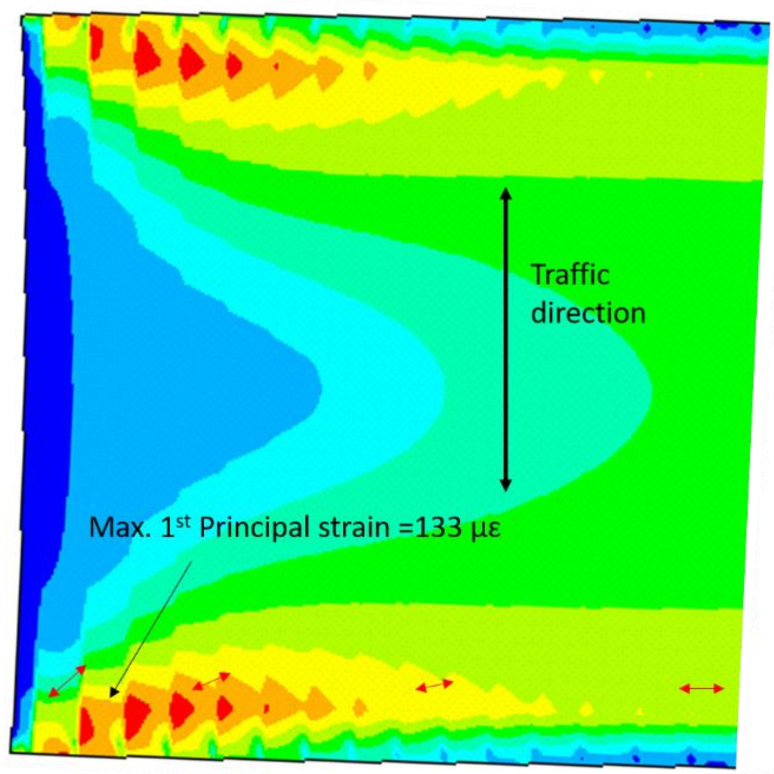


Figure 50. First principal strain on the bottom of the deck for FE Model 1 with isolation barrier

The maximum strain was approximately 133 microstrain, which is effectively equivalent to the concrete cracking strain of 132 microstrain as calculated using the equation $7.5\sqrt{f_c'}/57{,}000\sqrt{f_c'}$ (ACI 2011).

4.3 Efficacy of Thermal Isolation Barrier

The field monitoring results indicated that the thermal isolation barrier reduced the temperature difference between the front face (FF) and back face (BF) by about 10–15°F. However, the structural response to this temperature difference reduction is unknown.

To evaluate the influence of the isolation barrier on the deck structural behavior, the validated FE model was utilized and analyzed with the temperature distribution absent the isolation barrier, and the results were compared with those from the field monitoring and validated model.

The Viking Road Bridge was constructed with both abutments equipped with the thermal isolation barrier. Hence, the field condition did not allow for the measurement of the temperature distribution in absence of the thermal isolation barrier. However, this issue was overcome by estimating the temperature utilizing the current data with an assumption that the temperature data collection at the soil interface (SI) would be equal to the temperature at the back face (BF) of the abutment if the thermal isolation barrier did not exist (see the previous Figure 48 for the temperature distribution at the SI and BF sections). With this assumption, the temperature distribution was calculated utilizing the same approach as that used in Section 4.2.

The strain in the bridge transverse direction on the FE model (FE Model 2) at each VWSG location was output and compared with the results from the validated model and field monitoring in the previous Figure 49. The results indicated that the maximum transverse strain from a bridge without a thermal isolation barrier is approximately 141 microstrain, which is higher than the validated model and field monitoring results where the highest transverse strain was approximately 90 microstrain.

The first principal strain contour plot at the bottom surface of the bridge deck is presented in Figure 51, and the maximum strain is approximately 195 microstrain.

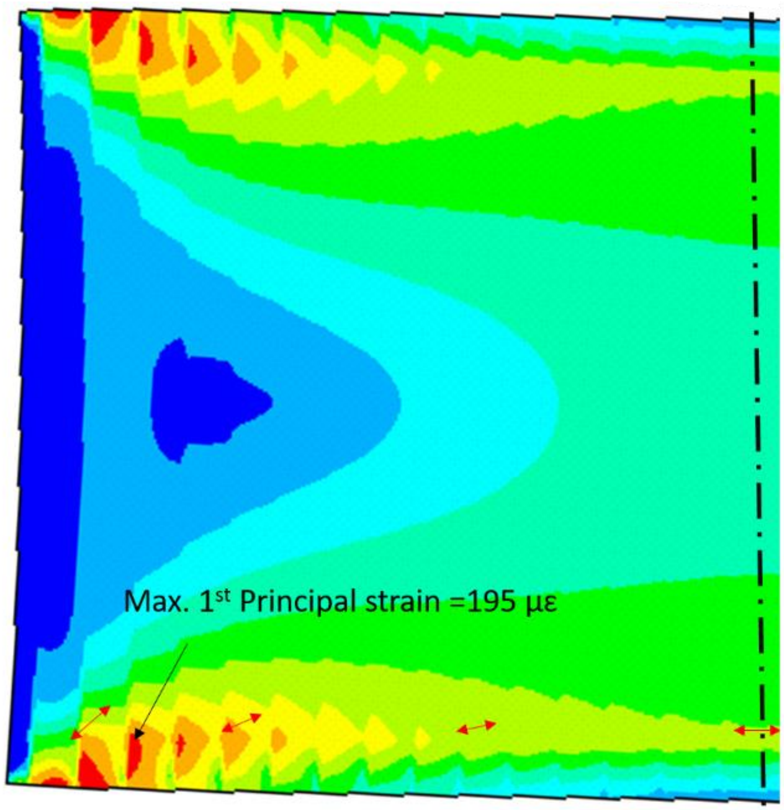


Figure 51. First principal strain on the bottom of the deck for FE Model 2 without isolation barrier

The FE model results indicated the maximum deck strain to be 46% greater without the thermal isolation barrier in place. Note that this strain already exceeds the concrete cracking strain of 132 microstrain as calculated by $7.5\sqrt{f_c'}/57{,}000\sqrt{f_c'}$ (ACI 2011). This indicated that, without the thermal isolation barrier, the Viking Road Bridge would be more likely to experience cracking at its deck end.

CHAPTER 5. SUMMARY AND CONCLUSIONS

Longitudinal bridge deck joints are commonly used in cases where the roadway carries a greater than typical number of traffic lanes. The longitudinal joints are thought to provide relief from expansion and contraction of the bridge deck resulting from temperature change, shrinkage, and live loads. Historically, however, these joints have been known to leak, allowing chloride-laden water to reach the bottom of the deck overhang and even the exterior girders.

The Phase I IHRB project TR-661 (Phares et al. 2015) was completed to determine the maximum width of a continuous deck that can be used without negatively impacting performance. One of the primary conclusions of this work was that the development of cracking in bridge decks seems less dependent on the total width of the deck and more dependent on restraint of the abutment when significant temperature gradients exist between the bridge deck and the very rigid abutment. Based on the FE results from that study, it was proposed that an effective solution to reduce cracking in the deck might be to place a thermal isolation barrier between the backfill soils and the back side of the abutment, thus maintaining closer temperatures within the abutment and bridge deck.

The objective of this research was to follow and document the design, construction, and performance of a newly constructed bridge in Black Hawk County with a specific focus on the success of the deck crack mitigation efforts. To achieve this objective, the bridge on Viking Road over IA 58 was selected to investigate the effects of a thermal isolation barrier.

The bridge in Black Hawk County was designed with a width of 228 ft, which is much greater than the maximum width of 60 ft before the use of a longitudinal joint is required per the Iowa Bridge Design Manual (Iowa DOT 2012). The bridge deck had no longitudinal expansion joints, only closure pours between adjacent deck pours, in which the deck reinforcement was continuous.

Using the recommendations from the previous research, a thermal isolation barrier was used between the backfill soils and the abutment. A more than two-year-long monitoring period followed the completion of construction using numerous thermistors and strain gauges at various abutment and deck locations. Additionally, periodic visual inspections were completed to identify if any deck cracks were forming. By the end of May 2022, nearly three years after construction completion, no evidence of deck cracking existed.

In addition, an analytical study was conducted using FE models to investigate the efficacy of the isolation barrier on the bridge deck end structural behavior. The models were calibrated and validated using field-collected strain and temperature data.

The results support the findings from the Phase I research that the development of cracking in bridge decks appears less dependent on the total width of the deck and more the result of differential temperatures between the bridge deck and integral abutment. The results indicated that a thermal isolation barrier is effective for limiting temperature differentials, which thereby limits the potential for deck end cracking on integral abutment bridges.

With a thermal isolation barrier, the temperature difference between the back face and front face at each level of the abutment remained relatively close throughout the year with differences being less than 10°F in most cases. The value of the thermal isolation barrier was especially apparent when ambient temperatures changed very quickly and a greater temperature differential was more likely.

The FE model results indicated that significantly higher deck strains exist when a thermal isolation barrier is not in place to limit the temperature differential through the thickness of the abutment. In fact, the maximum deck strain was found to be 46% greater when the thermal isolation barrier was not included. This indicated that, without the barrier, the strain values at the deck ends of the Viking Road Bridge could exceed the calculated cracking strain of the concrete.

The researchers recommend the use of a thermal isolation barrier between the abutment and backfill soils for wide integral abutment bridges as one way to lengthen the service life of these bridge decks while reducing maintenance, rehabilitation, and/or replacement costs as well.

REFERENCES

ACI 318-11. 2011. *Standard AA. Building Code Requirements for Structural Concrete.* American Concrete Institute, Farmington Hills, MI.

Cai, J., Y. Xu, J. Feng, and J. Zhang. 2012. Effects of Temperature Variations on the In-Plane Stability of Steel Arch Bridges. *Journal of Bridge Engineering*, Vol. 17, No. 2, pp. 232–240.

Iowa DOT. 2012. *LRFD Bridge Design Manual*. Iowa Department of Transportation Office of Bridge and Structures, Ames, IA.

Kim, W. and J. A. Laman. 2010. Numerical Analysis Method for Long-Term Behavior of Integral Abutment Bridges. *Engineering Structures,* Vol. 32, No. 8, pp. 2247–2257.

Lee, J.-H. 2012. Investigation of Extreme Environmental Conditions and Design Thermal Gradients During Construction for Prestressed Concrete Bridge Girders. *Journal of Bridge Engineering*, Vol. 17, No. 3, pp. 547–556.

Liu, Z., B. M. Phares, and L. F. Greimann. 2016. Use of Longitudinal Expansion Joints in Wide-Bridge Applications to Reduce Deck Cracking. *Journal of Bridge Engineering*, Vol. 21, No. 10, pp. 04016068-1–04016068-8.

Phares, B., L. Greimann, and Z. Liu. 2015. *Evaluation of the Need for Longitudinal Median Joints in Bridge Decks on Dual Structures*. Bridge Engineering Center, Iowa State University, Ames, IA.

Rodriguez, L. E. 2012. *Temperature Effects on Integral Abutment Bridges for the Long-Term Bridge Performance Program*. MS thesis. Utah State University, Logan, UT.

Rodriguez, L. E., P. J. Barr, and M. W. Halling. 2014. Temperature Effects on a Box-Girder Integral-Abutment Bridge. *Journal of Performance of Constructed Facilities*, Vol. 28, No. 3, pp. 583–591.

Xu, Y. L., B. Chen, C. L. Ng, K. Y. Wong, and W. Y. Chan. 2010. Monitoring Temperature Effect on a Long Suspension Bridge. *Structural Control and Health Monitoring*, Vol. 17, No. 6, pp. 632–653.

Yang, D.-H., T.-H. Yi, H.-N. Li, and Y.-F. Zhang. 2018. Monitoring and Analysis of Thermal Effect on Tower Displacement in Cable-Stayed Bridge. *Measurement*, Vol. 115, pp. 249–257.

THE INSTITUTE FOR TRANSPORTATION IS THE FOCAL POINT FOR TRANSPORTATION AT IOWA STATE UNIVERSITY.

InTrans centers and programs perform transportation research and provide technology transfer services for government agencies and private companies;

InTrans contributes to Iowa State University and the College of Engineering's educational programs for transportation students and provides K–12 outreach; and

InTrans conducts local, regional, and national transportation services and continuing education programs.

INSTITUTE FOR TRANSPORTATION

IOWA STATE UNIVERSITY

Visit **InTrans.iastate.edu** for color pdfs of this and other research reports.