GEORGIA DOT RESEARCH PROJECT 18-02

FINAL REPORT

IMPACT OF CONSTRUCTION LOADS ON STEEL DIAPHRAGM BRIDGE DESIGN

Georgia Department of Transportation

OFFICE OF PERFORMANCE-BASED MANAGEMENT AND RESEARCH

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16. Abstract:
Bridges are critical structures, serving an important function that is vital to the safe and economical conveyance of people and goods throughout Georgia. They are designed with specifications to carry loads including their self-weight and a design vehicle load, among others, when they are in service. Satisfying all design specifications is crucial to the structure's strength, stiffness, stability, and durability throughout its lifetime. In addition to the in-service dead and live load conditions, bridges are also designed to accommodate various loading conditions during the construction process. In some cases, these construction load and associated stability requirements are the governing load conditions for some of the bridges' components. Georgia Department of Transportation (GDOT) has recently allowed the substitution of steel diaphragms for concrete diaphragms in its bridges. This substitution is gaining popularity among contractors for its ease of construction and subsequent reduction of cost. Currently, there is no standardized design for GDOT steel diaphragms, and contractors are allowed to produce their own designs based on loading scenarios currently specified in the 2018 GDOT Bridge and Structures Design Manual. These scenarios include full long-term wind loadings and are thought to be overly conservative because the actual loads to which the bridges are subjected during the construction process are poorly understood. This project seeks to provide the data and recommendations for a more efficient, yet safe, steel diaphragm design. Specifically, this project will (1) observe and measure GDOT construction practices through visual observations by experts and by electronic sensors, (2) quantify the effects of the construction practices in terms of loadings via observations and computational models, (3) assess the overall impact of construction load variations on bridge designs, and (4) make recommendations to GDOT for loading specifications and for a standardized steel diaphragm design.

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IMPACT OF CONSTRUCTION LOADS ON STEEL DIAPHRAGM BRIDGE DESIGN

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November 2022

EXECUTIVE SUMMARY

Georgia Department of Transportation (GDOT) recently allowed the substitution of steel diaphragms for concrete diaphragms in its bridges. This substitution is gaining popularity among contractors for its ease of construction and subsequent reduction in cost. Currently, there is no standardized design for GDOT steel diaphragms, and contractors are allowed to produce their own designs based on loading scenarios currently specified in the 2018 GDOT Bridge and Structures Design Manual. These scenarios were thought to be overly conservative because the actual loads to which the bridges are subjected during the construction process are poorly understood.

Through in-situ bridge monitoring and finite element modeling, this project quantified the loads on multiple k-frame diaphragms on a single bridge during the construction process, specifically during concrete deck pouring. The monitoring and modeling determined that the wind loads, specified by American Association of State Highway and Transportation Officials (AASHTO), produced strains that were greater than the construction loads for the members that were monitored (diagonal members and chords). Additional testing is needed to determine the behavior of the gusset plate and to verify connections under the wind loading, which was not monitored as part of the research effort.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should comply with Section 4 of ASTM E380. (Revised March 2003)

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CHAPTER 1. INTRODUCTION

RESEARCH MOTIVATION

Bridges are critical structures, serving an important function that is vital to the safe and economical conveyance of people and goods throughout Georgia. They are designed with specifications to carry loads including their self-weight and a design vehicle load, among others, when they are in-service. Satisfying all design specifications is crucial to the strength, stiffness, stability, and durability of the structure throughout its lifetime. In addition to the in-service dead and live load conditions, bridges are also designed to accommodate various loading conditions during the construction process. In some cases, these construction load and associated stability requirements are the governing load conditions for some of the bridges' components.

Georgia Department of Transportation (GDOT) has recently allowed the substitution of steel diaphragms for concrete diaphragms in its bridges, as shown in Figure 1 and Figure 2.[(1)] This substitution is gaining popularity among contractors for its ease of construction and subsequent reduction of cost. Currently, there is no standardized design for GDOT steel diaphragms, and contractors are allowed to produce their own designs based on loading scenarios currently specified in the 2018 GDOT Bridge and Structures Design Manual. These scenarios include full long-term wind loadings and are thought to be overly conservative because the actual loads to which the bridges are subjected during the construction process are poorly understood. This project seeks to provide the data and recommendations for a more efficient, yet safe, steel diaphragm design. Specifically, this project will (1) observe and measure GDOT construction practices through visual observations by experts and by electronic sensors, (2) quantify the effects of the construction practices in terms of loadings via observations and computational models, (3) assess the overall impact of construction load variations on bridge designs, and (4) make recommendations to GDOT for loading specifications and for a standardized steel diaphragm design.

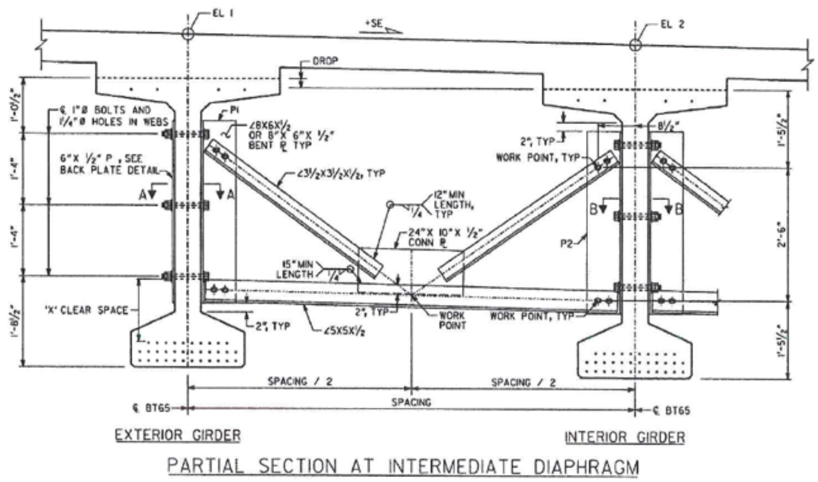


Figure 1. Engineering drawing. Partial section at intermediate diaphragms

Figure 2. Photo. Intermediate k-frame diaphragms in situ

BACKGROUND

Standard specifications from multiple states' departments of transportation (DOTs) show a wide variety of construction load approaches for dead, live, wind, and impact loadings.[2-16] The specifications from each state adopt their own combination of practices, the majority of which are derived from the *AASHTO Guide Design Specifications for Bridge Temporary Works* and *ASCE 37: Design Loads during Construction*.[17-18] The state DOTs' approaches vary in terms of the magnitude of load and the construction phases in which the loads apply.

In addition to the loading specifications, the state agencies also differ in terms of their acceptance and design requirements for diaphragms. GDOT has historically solely recommended the use of concrete diaphragms in its bridges; however, the current *2018 GDOT Bridge and Structures Design Manual* has the following provision regarding the substitution of steel diaphragms for certain conditions in Section 3.9.1.1:

> *"Steel Diaphragms – at the contractor's option, steel diaphragms may be used in lieu of the concrete diaphragms shown in the plans. At a minimum, steel diaphragms are to be designed for applied wind load. Stability of the beams and structure during all phases of construction are the sole responsibility of the contractor. Submit shop drawings and calculations for the steel diaphragms to the engineer for review and acceptance."*

Since the introduction of this provision, a relatively small number of contractors have chosen the steel diaphragm option and have provided GDOT with new designs and supporting calculations for acceptance checks. Two examples of these designs are shown in Figure 3 and Figure 4. From the figures, it is apparent that two designs, while meeting the current standard, are drastically different in both geometry and sizing. GDOT expects that the number of instances of steel diaphragm substitution will continue to increase due to its ease of construction and reduced cost for the contractor. Because of this, GDOT is interested in understanding the construction and other loads on these systems such that the design can be standardized.

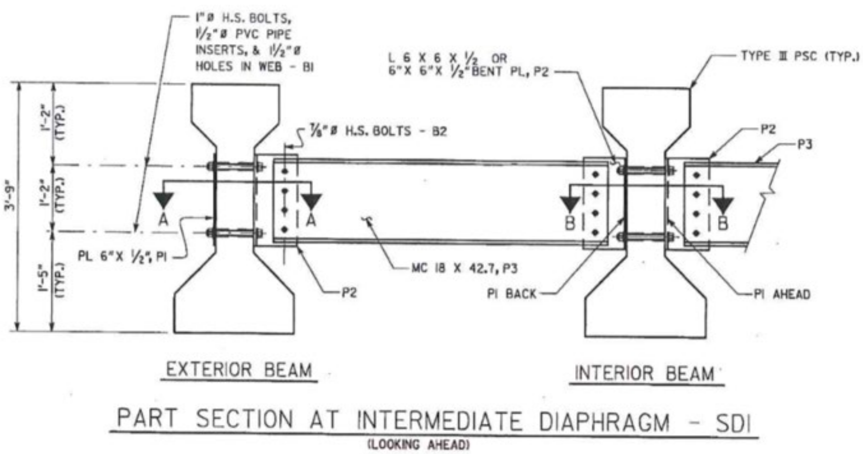


Figure 3. Engineering Drawing. Example of existing GDOT solid plate with MC section diaphragms

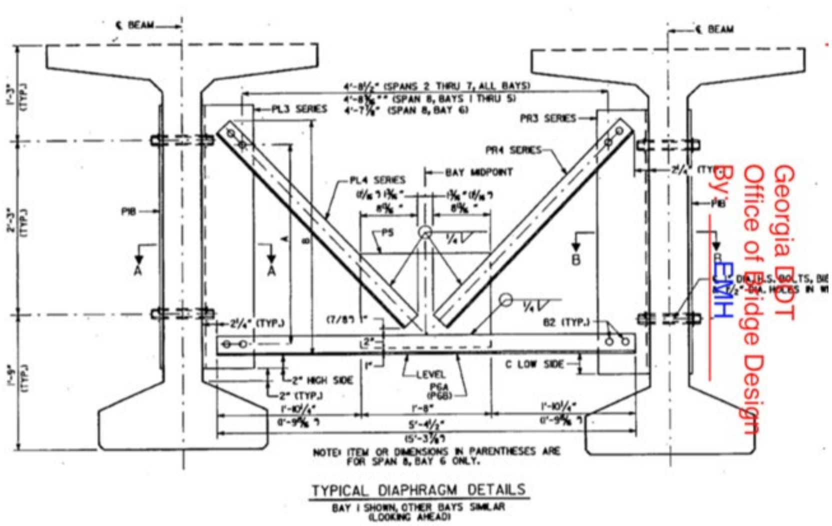


Figure 4. Engineering Drawing. Example of existing GDOT k-frame diaphragm

Currently, the load considered for the design of the steel diaphragms is wind load. The calculations are done in accordance with the windward load as illustrated in AASHTO Table 3.8.1.2.1-1, shown in Figure 5. As indicated in the table, the minimum load used for design should be 0.3 klf in the plane of the windward chord. Chapter 2 provides an example of the current design practice.

Table 3.8.1.2.1-1—Base Pressures, P_B, Corresponding to V_B = 100 mph

Superstructure Component	Windward Load, ksf	Leeward Load, ksf
Trusses, Columns, and Arches	0.050	0.025
Beams	0.050	NA
Large Flat Surfaces	0.040	NA

The total wind loading shall not be taken less than 0.30 klf in the plane of a windward chord and 0.15 klf in the plane of a leeward chord on truss and arch components, and not less than 0.30 klf on beam or girder spans.

Figure 5. Excerpt. Table 3.8.1.2.1-1. from AASHTO[17]

OBJECTIVES

The objectives of this research are as follows:

1) To understand the loads on steel diaphragm bridges during the construction process through visual observation of bridge construction.
2) To measure the effect of construction loads on steel diaphragm bridges during construction via sensors.
3) To quantify the construction loads on the structure using the observations and measured data combined with computational and analytical models.
4) To draft recommended practices (e.g., construction loads) for GDOT steel diaphragm design.

REPORT ORGANIZATION

Chapter 2 of this report gives an example of a typical diaphragm design based on AASHTO 3.8.1.2.1.1. This example will be referenced in additional examples of the report. Chapter 3 describes the site visits that were conducted throughout the project and discusses the selection of the bridge for monitoring. Chapter 4 details a laboratory effort that was used to validate the sensors for field monitoring. Chapter 5 contains details on the bridge monitoring effort, including logistics, setup, and results. Chapter 6 explains the three finite-element modeling efforts that were conducted based on the monitoring. Chapter 7 provides the conclusions and recommendations.

The five appendices contain example design calculations (Appendix A), time-lapse photos (Appendix B), MATLAB codes (Appendix C), unfiltered data (Appendix D), and concrete construction load calculations (Appendix E).

CHAPTER 2. EXAMPLE CURRENT DESIGN PROCESS

To illustrate the typical process used for design per AASHTO, this chapter provides an example calculation. This example was submitted to GDOT by a contractor. In this example, A Bulb Tee 63 (BT-63) girder-type bridge with the properties and dimensions was considered (Table 1).

Table 1. Example Bridge Properties

Bridge Element	Dimensions / Property
Longest Girder Length, L	124 ft
Girder Material	Concrete
Girder Type	BT-63
Girder Cross Section Area, A	4.95 ft^2
Girder Height, H	4.5 ft

The wind pressure per linear foot, w_{plf}, is calculated according to AASHTO Table 3.8.1.2.1.1 as the 50 psf multiplied by the girder height and should not be taken to be less than 300 plf. For this bridge, the calculations are shown the grouping of equations given in Figure 6.

$$
\begin{aligned}
w_{plf} &= \max\{50 \text{ psf} \times \text{H}, 300 \text{ plf}\} \\
w_{plf} &= \max\{50 \text{ psf} \times 4.5 \text{ ft}, 300 \text{ plf}\} \\
w_{plf} &= \max\{225 \text{ plf}, 300 \text{ plf}\} \\
w_{plf} &= 300 \text{ plf}
\end{aligned}
$$

Figure 6. Equations. Bridge wind load calculations.

To obtain the concentrated wind force, w_{TWL}, the value of load per linear foot, w_{plf}, is multiplied by the longest girder length as shown by the grouping of equations (Figure 7).

$$w_{TWL} = w_{plf} \times L$$
$$w_{TWL} = 300 \text{ plf} \times 124 \text{ ft}$$
$$w_{TWL} = 37{,}200 \text{ lb} = 37.2 \text{ kips}$$

Figure 7. Equations. Concentrated wind force calculations.

The diaphragm is loaded with 50 percent of the girder length for the wind load. Therefore, the total wind load is divided by two, and thus half of the wind load, w_{HWL}, applied to the diaphragm is 18.6 kips.

The application of load is dependent on the type of diaphragm chosen. In the case of a solid plate with MC sections, the one-half wind load is applied at one end of the diaphragm for the analysis. For the k-frame diaphragms with L sections, the half wind load is divided by two, and that value is applied to the top diagonal and bottom member horizontal leg as a lateral load on the wind face of the diaphragm, chosen to be the right side in Figure 6. Because k-frame diaphragms are most of interest to GDOT, the analysis will be continued for that example.

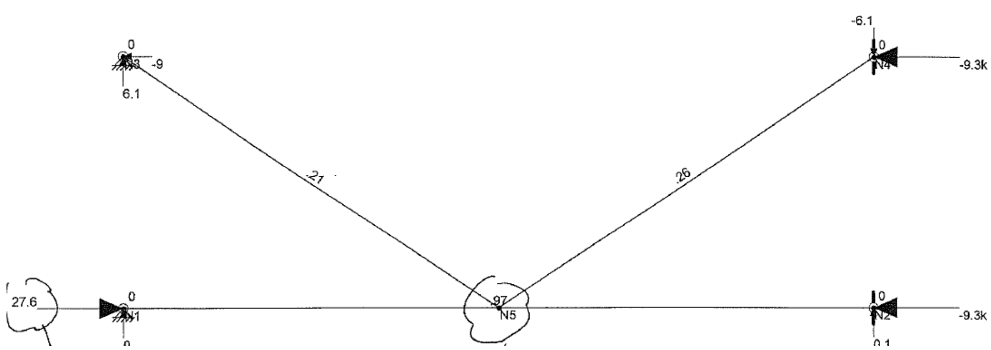


Figure 8. Engineering Drawing. Example wind loading of k-frame Diaphragm

Analysis of the structure was completed in RISA-3D and the internal forces and moments in all the members were determined (Figure 9).[19] The Allowable Strength Design direct analysis method is used for design of the steel members and bolts, whereby no load factors are used. The members of the diaphragm are designed with this method (Figure 8). Appendix A contains additional design calculations provided to GDOT contractor. These calculations provide additional design checks on the bolted connections.

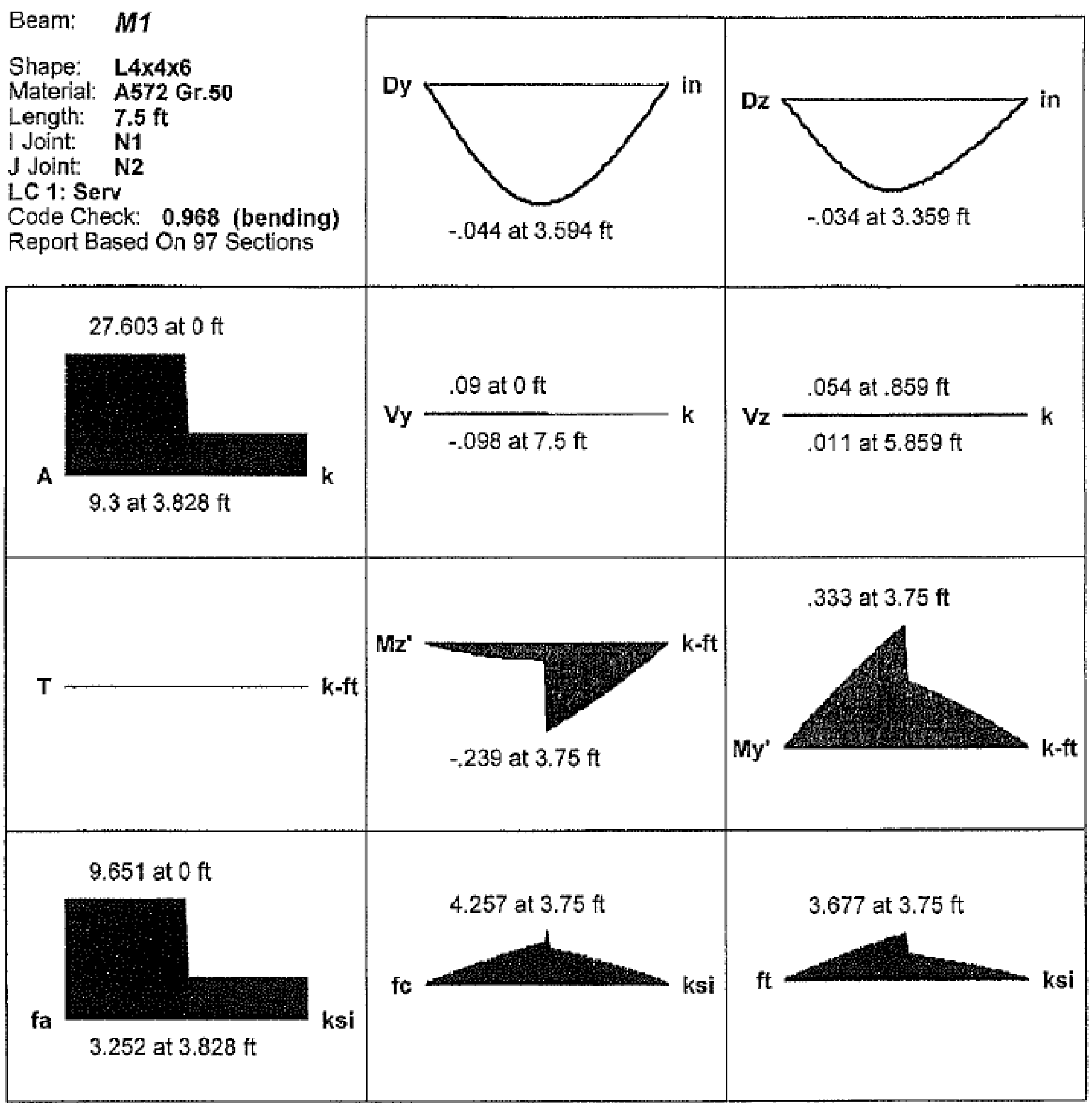
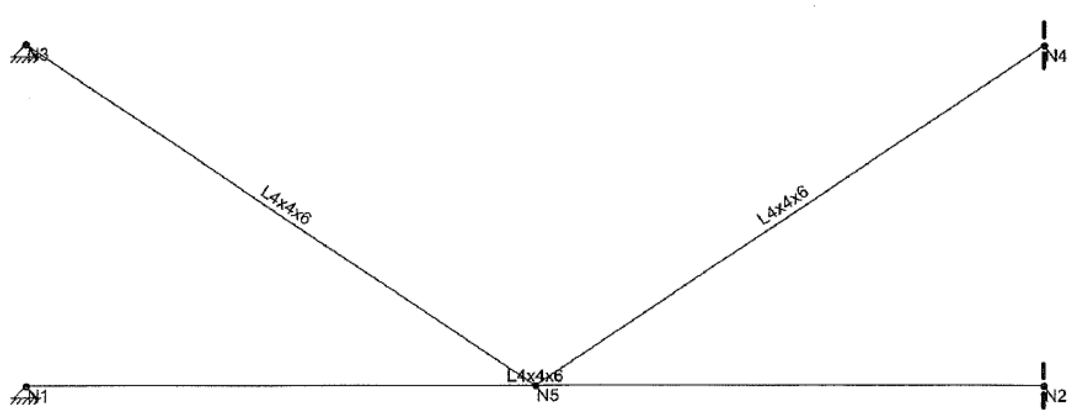


Figure 9. Calculation. Example wind load internal forces (from RISA)



Member Primary Data

	Label	I Joint	J Joint	K Joint	Rotate(deg)	Section/Shape	Type	Design List	Material	Design Rules
1	M1	N1	N2			L4x3	Beam	Single Angle	A572 Gr.50	Typical
2	M2	N3	N5			L4x3	Beam	Single Angle	A572 Gr.50	Typical
3	M3	N4	N5			L4x3	Beam	Single Angle	A572 Gr.50	Typical

AISC 14th(360-10): ASD Code Check

Direct Analysis Method

Max Bending Check	**0.968**	Max Shear Check	**0.004 (y)**	Max Defl Ratio	**L/2034**
Location	**3.75 ft**	Location	**7.5 ft**	Location	**3.594 ft**
Equation	**H2-1**			Span	**1**

Bending Flange	**Compact**	Compression Flange	**Non-Slender**
Bending Web	**Compact**	Compression Web	**Non-Slender**

			y-y'	z-z'
Fy	**50 ksi**	Lb	**7.5 ft**	**7.5 ft**
Pnc/om	**32.206 k**	KL/r	**115.533**	**57.924**
Pnt/om	**85.629 k**			
Mny'/om	**4.065 k-ft**	L Comp Flange	**7.5 ft**	
Mnz'/om	**8.12 k-ft**	L-torque	**7.5 ft**	
Vny/om	**26.946 k**	Tau_b	**1**	
Vnz/om	**26.946 k**			
Cb	**1.455**			

Figure 10. Calculation. Example wind load member design

CHAPTER 3. BRIDGE VISITS AND OBSERVATIONS

Because construction loads are not typically included in the AASHTO design, it was important for the team to monitor a bridge throughout its construction. Multiple active bridge sites with different steel diaphragm configurations, particularly k-frame and single chord diaphragms, were visited to identify bridges that would potentially be used in the monitoring stage and to plan the monitoring. A summary of the bridge visits with purpose is given in Table 2.

Table 2. Summary of Bridge Site Visits

Date	Location	Purpose
02/01/2019	Macon, I16-I75 Bridge https://goo.gl/maps/YjS87Azzw9ZsYjgP8	Conduct preliminary site visit to observe the different installed diaphragms on the bridge
03/20/2019	Macon, I16-I75 Bridge https://goo.gl/maps/YjS87Azzw9ZsYjgP8	Observe status of the bridge post construction updates and identify potential spans to instrument
03/21/2019	Macon, I16-I75 Bridge https://goo.gl/maps/YjS87Azzw9ZsYjgP8	Install time-lapse camera and capture time-lapse footage during deck pour
05/29/2019	Longstreet Bridge Gainseville, GA 30506 https://goo.gl/maps/z6s3z5eBUVDBmYQD6	Observe diaphragm installation and placement
10/24/2019	Macon, I16-I75 Bridge, Bridge 11B, Span 25RT	Conduct dry run installation of strain gauges onto a single chord diaphragm
11/01/2019	Macon, I16-I75 Bridge, Bridge 11B, Span 25RT	Test wireless data communication during deck pouring process and capture time-lapse footage
08/13/2020	Macon, I16-I75 Bridge, Bridge 11B, Span 14	Instrumentation of exterior bay diaphragm (bay 1) with strain gauges
08/14/2020	Macon, I16-I75 Bridge, Bridge 11B, Span 14	Instrumentation of interior bay diaphragm (bay interior 3) with strain gauges
08/21/2020	Macon, I16-I75 Bridge, Bridge 11B, Span 14	Troubleshoot installed sensors on site and test wireless communication post installation
08/26/2020	Macon, I16-I75 Bridge, Bridge 11B, Span 14	Conduct wireless data collection during concrete deck pouring process

During the site visit on May 29, 2019, the installation of the steel diaphragm was observed (Figure 7). The diaphragms are preassembled according to the steel drawing and then lifted and placed between the girders via a crane. The side angles are then bolted into the girders. This method is both practical and efficient in terms of resources including cost, time, and labor and is often the reason that contractors choose to replace the concrete diaphragms with the steel option.

Figure 11. Photo. Installation of k-frame diaphragm

During site visit on March 21, 2019, span 25RT of Bridge 11B in the I-16/I-75 Interchange project in Macon was monitored with two time-lapse cameras during the concrete deck pouring. Figure 8 shows a single image of this time lapse. The time lapse was examined to identify the sources of construction loads acting on the diaphragms. After reviewing the captured footage, the main sources of loading identified were the concrete pour and the concrete pavement machine. Before the slab is placed and the concrete sufficiently hardens, the steel cross frame diaphragms help limit rotations and twisting distortions in the concrete girders, as well provide lateral stiffness to the bridge. Appendix B contains a series of images from the time lapse.

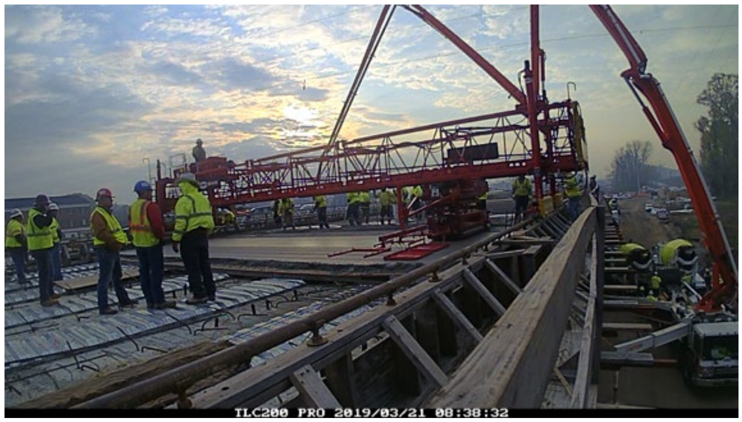


Figure 12. Photo. Still from time-lapse camera during concrete deck pour

After visiting multiple bridge sites using steel diaphragms in prestressed reinforced concrete girder bridges in Georgia, a bridge in Macon was selected for instrumentation and monitoring. The bridge was selected mainly for the installation and deck pouring time frame as well as accessibility to the diaphragms using a bucket truck. More specifically, the bridge studied was located at the interchange of Interstate I75 in Macon, Georgia. Figure 9 shows a map of the location, and Figure 10 shows a satellite image of the bridge. The interchange is currently under construction in the satellite image.

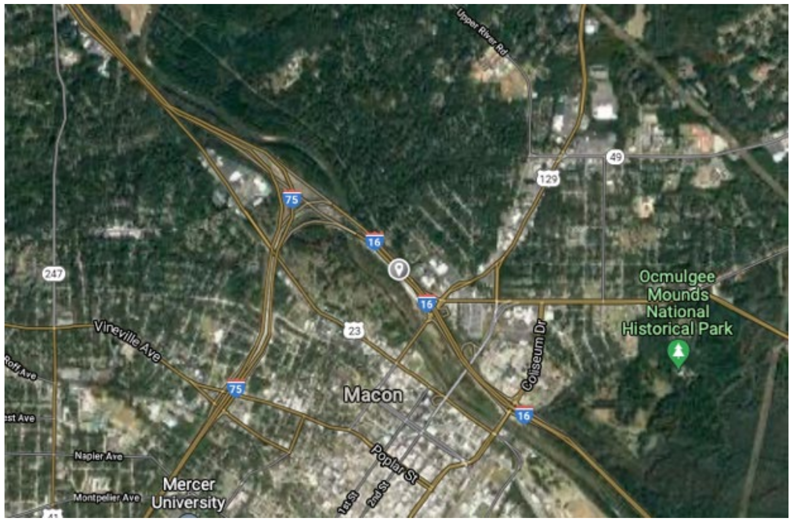


Figure 13. Map. Bridge location

Figure 14. Map. Satellite view of bridge span to be instrumented

The selected bridge consists of prestressed concrete girders (PSC) with steel diaphragms and concrete deck slab. More specifically, span 25RT was chosen for instrumentation and span 14 were chosen for instrumentation and monitoring. Span 25RT was used to ensure our instrumentation process was adequate and test our data acquisition system using our wireless sensing system. Span 14 was chosen for instrumentation and monitoring during the concrete deck pouring process. Chapter 5 explains each field test in detail.

CHAPTER 4. LABORATORY TESTING

Before the monitoring occurred, an experimental effort was conducted to validate the wireless sensing system, Martlet, which was used for the bridge test. This chapter explains the Martlet system, provides details on the test setup, and summarizes the results of the validation testing.

MARTLET SYSTEM

The wireless sensing system, named *Martlet*, which was developed by Georgia Tech researchers and collaborators.[(20-22)] The data acquisition was done wirelessly, via the wireless sensing system Martlet (Figure 11) and via National Instrument cabled data acquisition (NI DAQ). An advantage of the wireless sensing system is that it can be conveniently installed and used, particularly in a cluttered construction site. The wireless sensing unit (WSU) consists of the battery board and the mother board as well as a 24bit ADC board (Figure 12) used for data collection. Martlet uses a Texas Instruments Piccolo microcontroller (TMX320F28069) as the core processor, which can be programmed based on different needs and tasks.

Figure 15. Photo. Martlet wireless sensing unit (WSU)

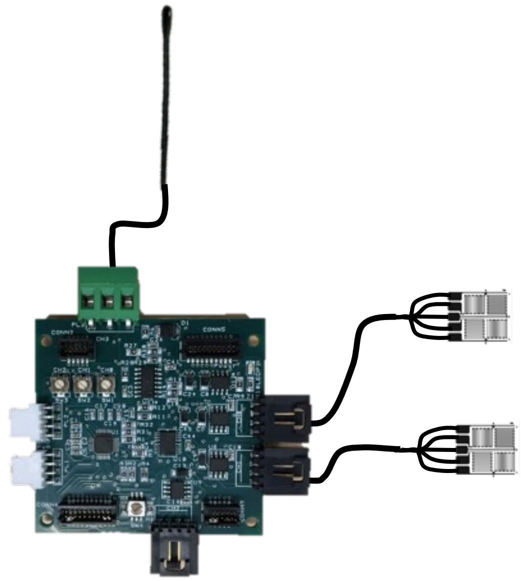
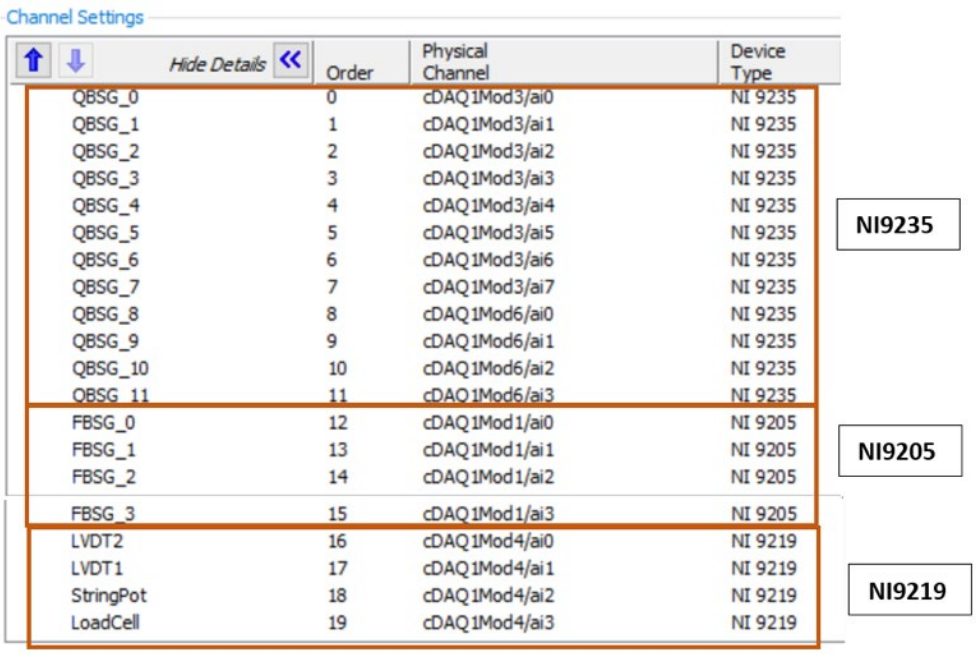


Figure 16. Photo. 24-bit ADC sensor board

In terms of wireless data acquisition, all units were prepared and programmed accordingly. Note that in addition to strain gauges, a thermistor was also used in each Martlet unit to obtain temperature readings. For the cabled data acquisition, all the electrical wiring was connected appropriately. A file was prepared in LabView to process the strain, load, and deflection signals. The different cabled sensors used along with the corresponding NI cards are delineated in Figure 13.



Channel Settings

Hide Details	Order	Physical Channel	Device Type
QBSG_0	0	cDAQ1Mod3/ai0	NI 9235
QBSG_1	1	cDAQ1Mod3/ai1	NI 9235
QBSG_2	2	cDAQ1Mod3/ai2	NI 9235
QBSG_3	3	cDAQ1Mod3/ai3	NI 9235
QBSG_4	4	cDAQ1Mod3/ai4	NI 9235
QBSG_5	5	cDAQ1Mod3/ai5	NI 9235
QBSG_6	6	cDAQ1Mod3/ai6	NI 9235
QBSG_7	7	cDAQ1Mod3/ai7	NI 9235
QBSG_8	8	cDAQ1Mod6/ai0	NI 9235
QBSG_9	9	cDAQ1Mod6/ai1	NI 9235
QBSG_10	10	cDAQ1Mod6/ai2	NI 9235
QBSG_11	11	cDAQ1Mod6/ai3	NI 9235
FBSG_0	12	cDAQ1Mod1/ai0	NI 9205
FBSG_1	13	cDAQ1Mod1/ai1	NI 9205
FBSG_2	14	cDAQ1Mod1/ai2	NI 9205
FBSG_3	15	cDAQ1Mod1/ai3	NI 9205
LVDT2	16	cDAQ1Mod4/ai0	NI 9219
LVDT1	17	cDAQ1Mod4/ai1	NI 9219
StringPot	18	cDAQ1Mod4/ai2	NI 9219
LoadCell	19	cDAQ1Mod4/ai3	NI 9219

Figure 17. Photo. Cabled DAQ setup using NI

LABORATORY SPECIMEN

At Georgia Tech, a full-scale replica of one of the k-frame steel diaphragms approved by GDOT was fabricated in the machine shop at Georgia Tech. Drawings of the k-frame are shown in Figure 16, Figure 17, and Figure 18. The k-frame consists of a L5x5x0.5 bottom chord member connected to two L3.5x3.5x0.5 diagonal members via a 0.25-inch-thick gusset plate. Furthermore, the opposite ends of the diagonal members are connected to L8x6x0.5 angles. From the drawings, the steel members were cut and assembled by bolting together the appropriate members. The full-scale replica is shown in Figure 19.

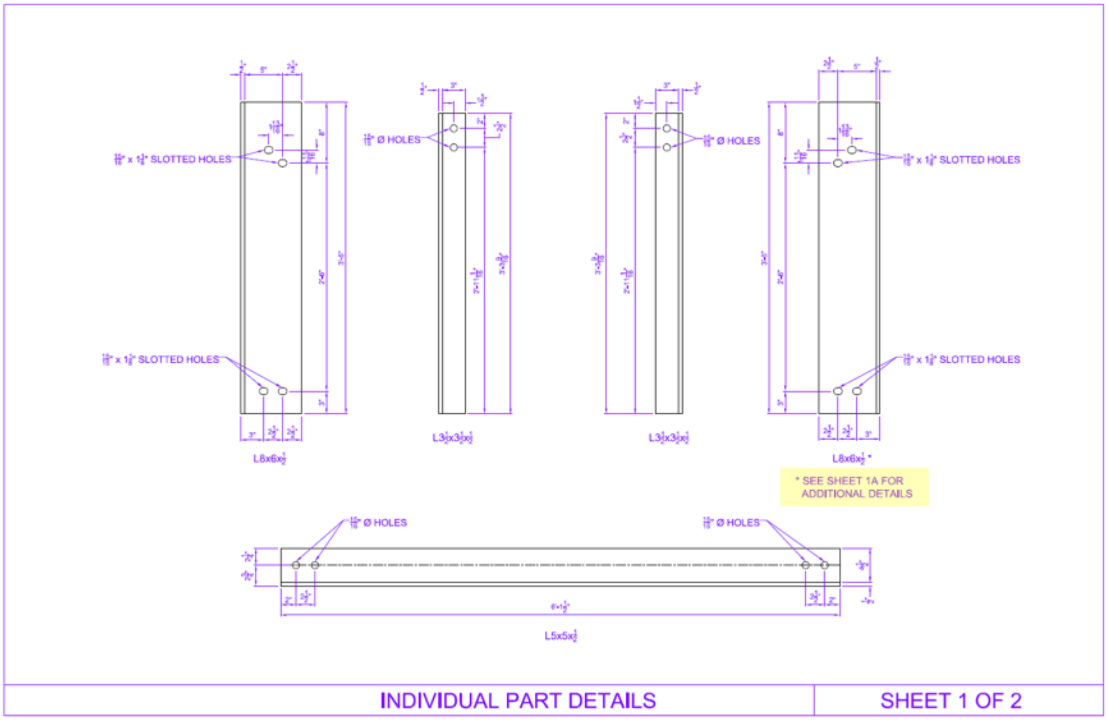


Figure 18. Engineering Drawing. Fabricated k-frame replica (1 of 3)

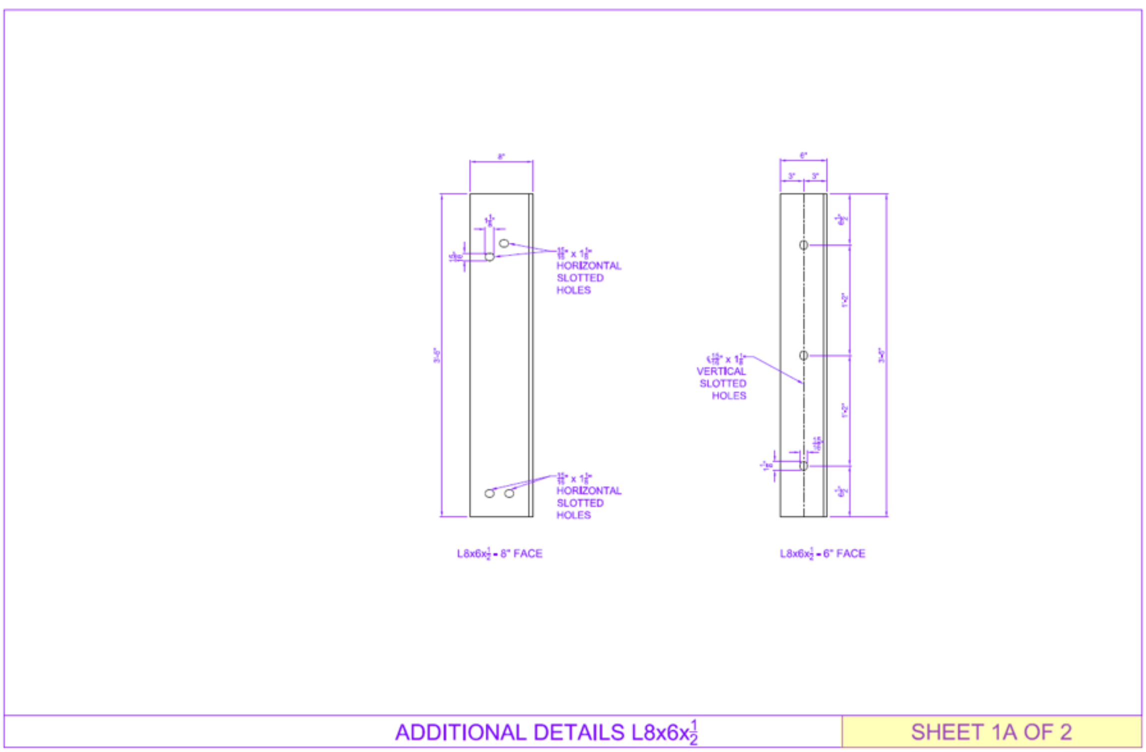


Figure 19. Engineering Drawing. fabricated k-frame replica (2 of 3)

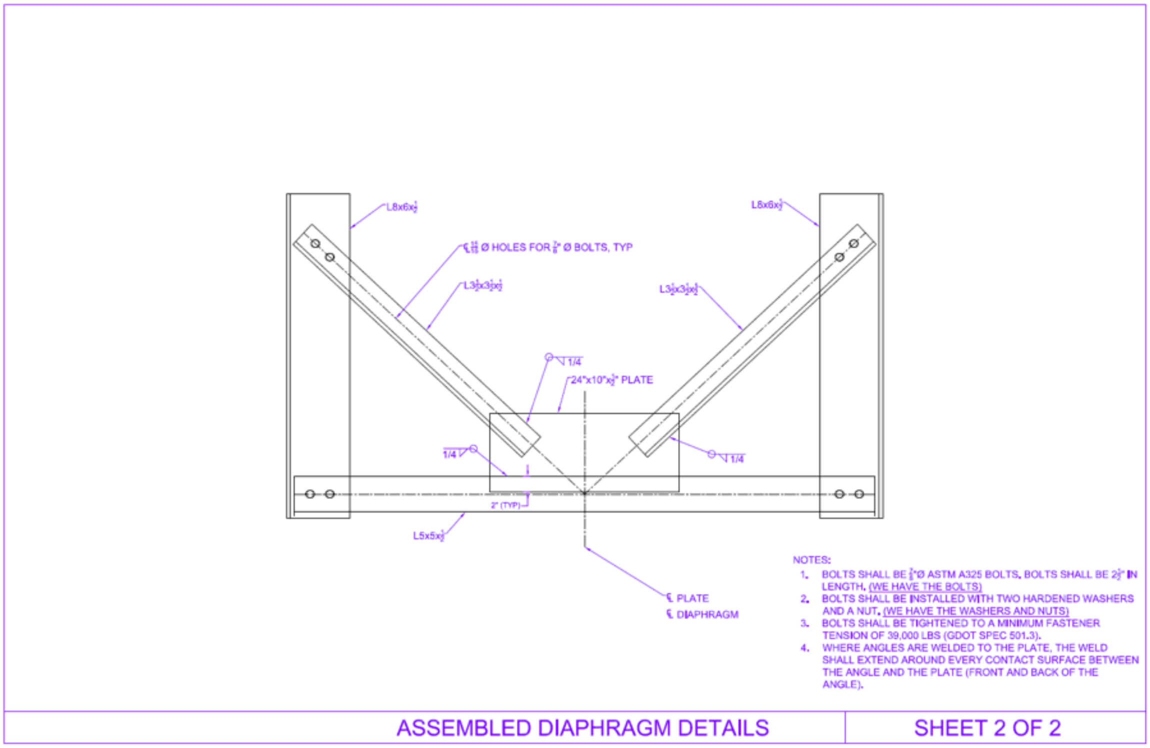


Figure 20. Engineering Drawing. Fabricated k-frame replica (3 of 3)

Figure 21. Photo. Frabricated k-frame replica

TEST SETUP

The purpose of the experiment was to validate the wireless sensing network against cabled sensors and confirm that the wireless sensors can perform continuous monitoring. To apply loads onto the test specimen and measure the induced strain, an experimental setup was designed and built in the Structural Engineering and Materials Laboratory at the Georgia Institute of Technology. A sketch of the setup is shown in Figure 19. A load cell was mounted onto a column, which was held in position by two transverse beams screwed tightly into the strong floor, also shown in Figure 19. The specimen was bolted to the plate, which, in turn, was bolted onto the rigid frame, as shown in Figure 20.

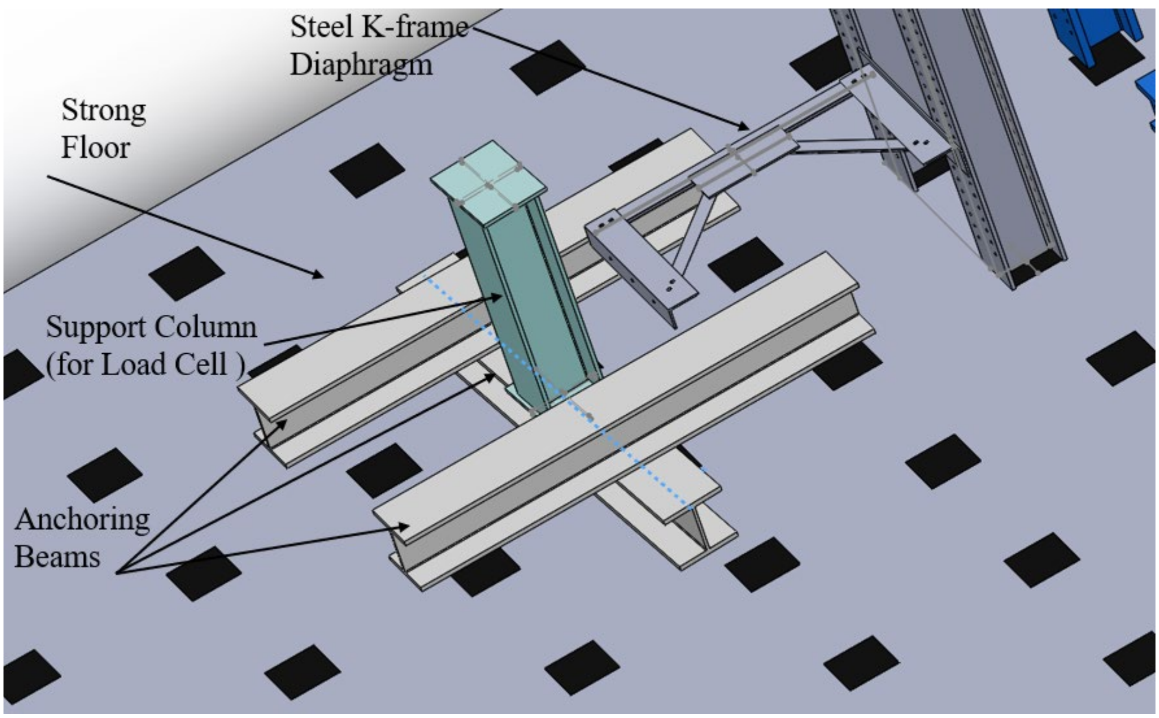


Figure 22. Schematic. Laboratory setup

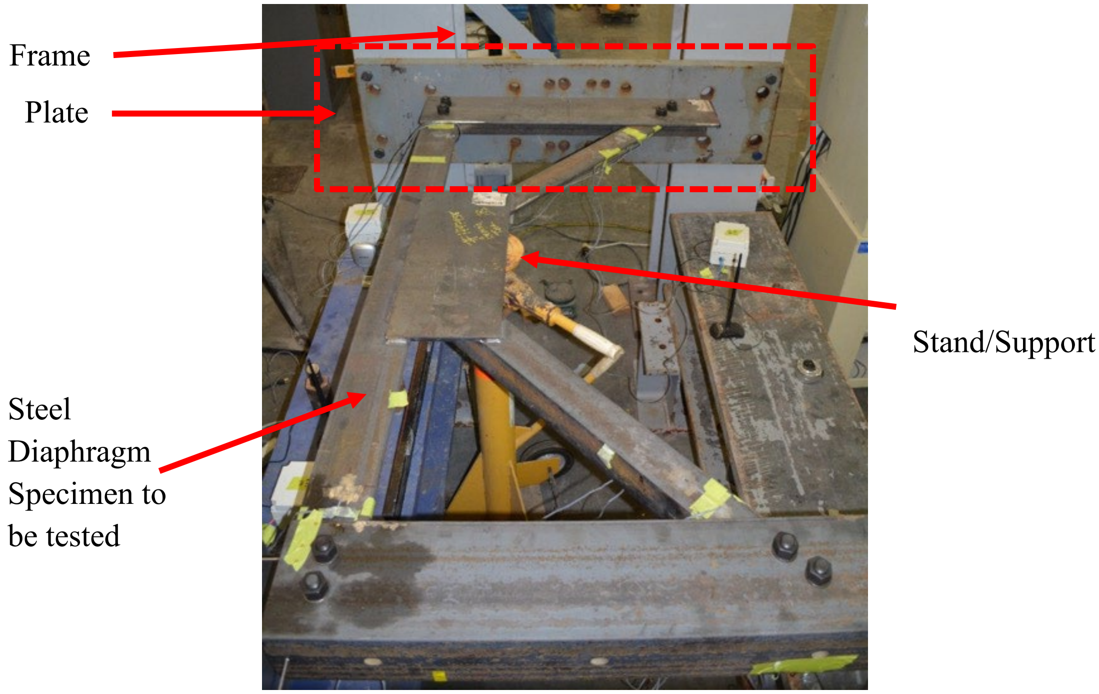


Figure 23. Photo. Laboratory setup of the steel diaphragm

The specimen was either supported by a stand or by the crane at its middle, as shown in Figure 21. The crane was used for support before loading. Once enough load was placed onto the system to ensure stability, the crane was released, and the testing was continued.

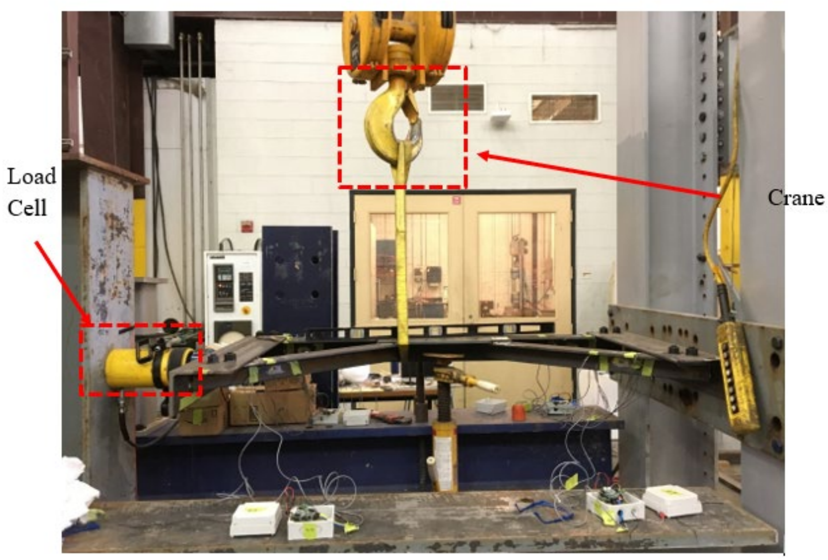


Figure 24. Photo. Laboratory setup with crane

INSTRUMENTATION

The diaphragm specimen was equipped with a network of both cabled and wireless strain gauges to measure strains at various locations, as well as linear variable displacement transducers (LVDTs), a string potentiometer to measure displacement, and thermistors to measure temperature.

An array of different strain gauges was used that included 12 quarter bridge strain gauges and 12 full bridge strain gauges. Figure 25 illustrates the locations of the instrumented strain gauges along with the type and mode of data acquisition. To install the gauges, the surface of the diaphragm was thoroughly cleaned until bare steel surface was reached, and the strain gauges were mounted onto the diaphragm at the selected locations (Figure 26).

To obtain displacement measurements, three displacement sensors were used, and their locations are shown in Figure 27. One string potentiometer (SP1A) was used to measure the out-of-plane deflections, and two linear variable differential transformers (LVDT1 and LVDT 2) were used to measure in-plane deflection in both directions shown. The LVDTs were fixed to the support columns (Figure 28). The string potentiometer was connected to the angle and placed on the ground vertically below the member (Figure 29).

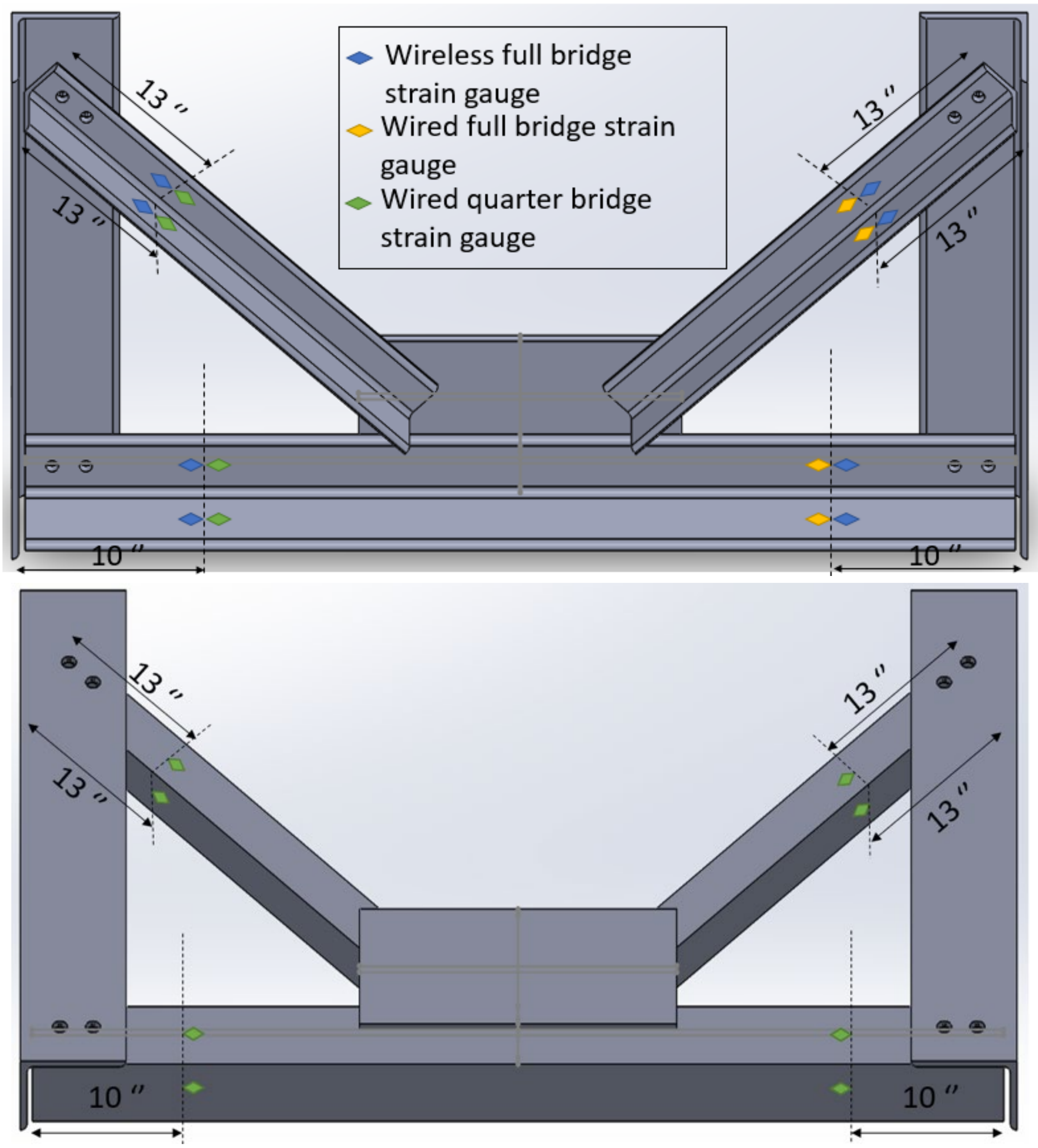


Figure 25. Schematic. Strain gauge instrumentation layout

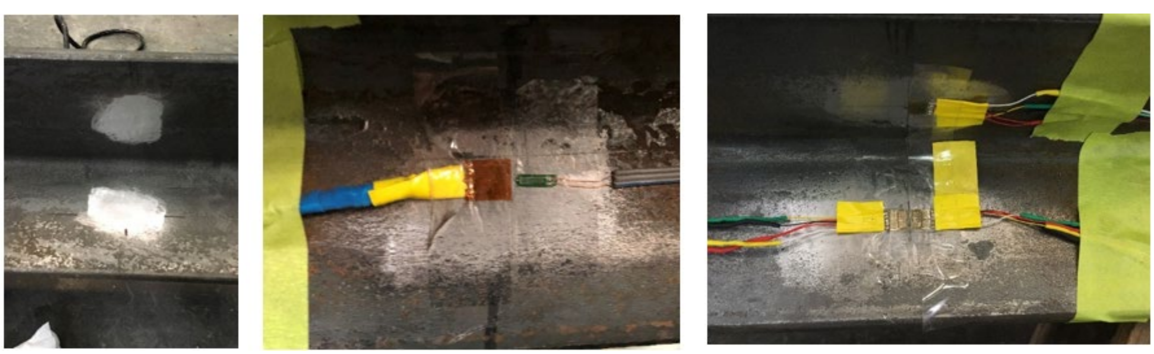


Figure 26. Photo. Cleaning of surface and instrumentation of strain gauges onto the diaphragm

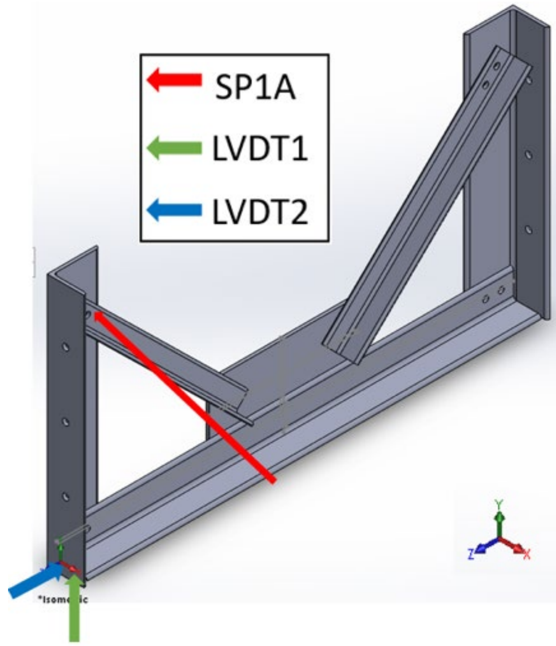


Figure 27. Schematic. Displacement sensor layout

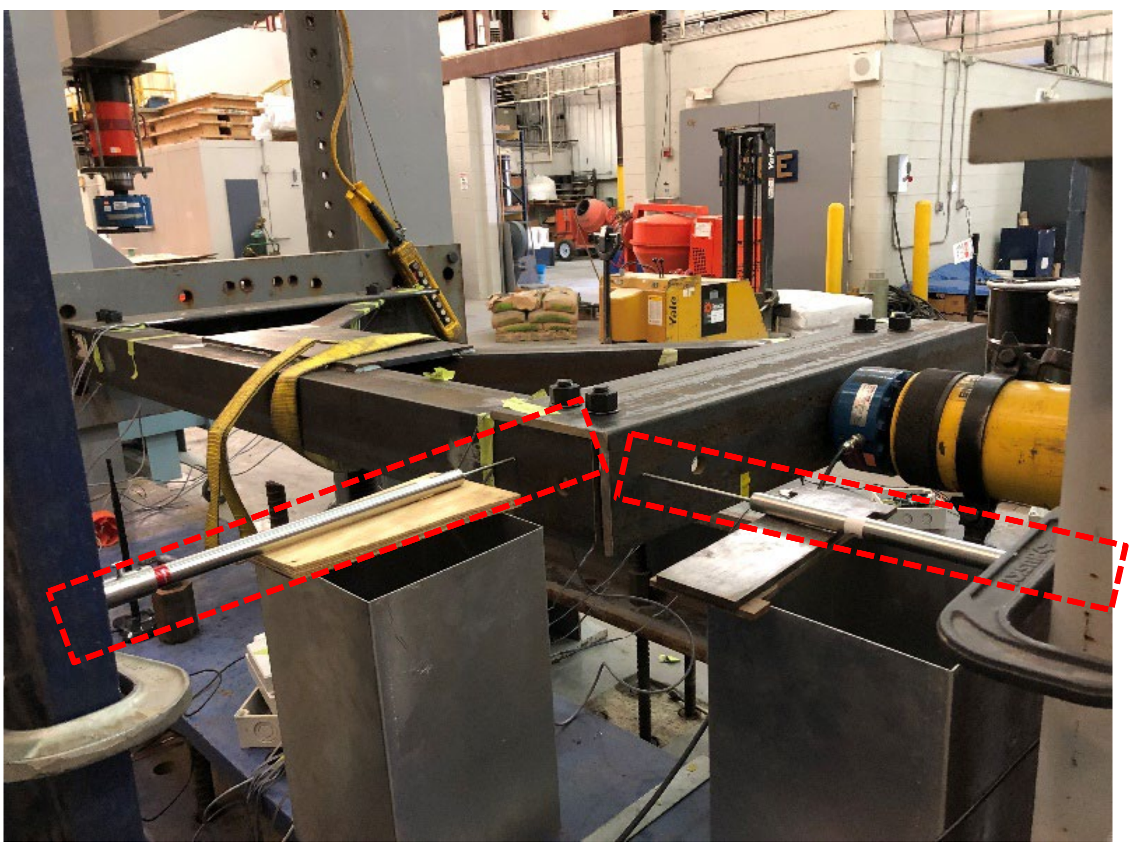


Figure 28. Photo. Setup of LVDT displacement sensors to measure in-plane deflections

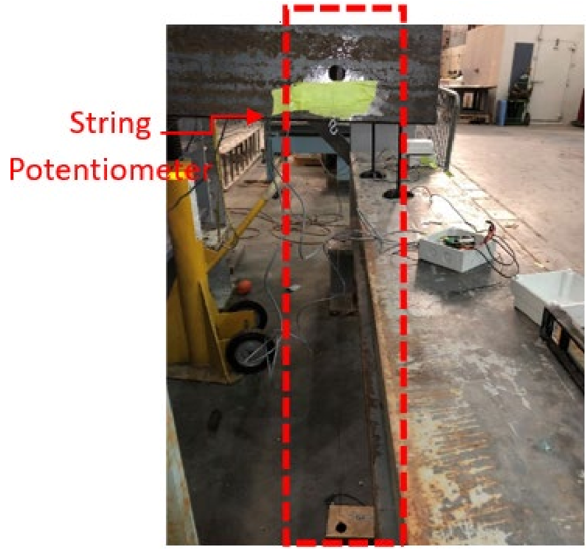


Figure 29. Photo. Setup of string potentiometer to measure out-of-plane deflections

TESTING PROCEDURE

The tests consisted of either loading continuously up to a certain limit, which was determined via a finite element model or by loading in steps of 2 kips until the maximum load was reached to mimic concrete deck pouring stages. Once the maximum load was reached, the load was kept for a specified duration. Unloading was also done either in steps or continuously until fully unloaded. Data were continuously collected throughout the entire process. Figure 30 provides a summary of the loading procedure.

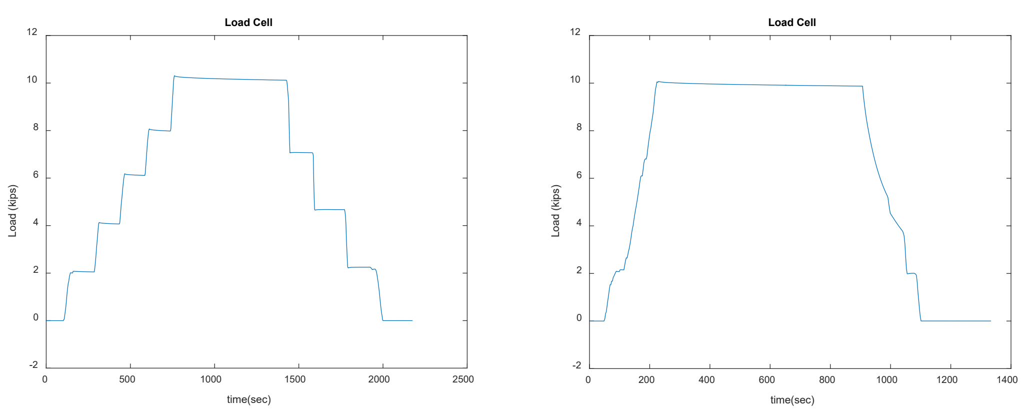


Figure 30. Graph. Variation of the load as a function of time when loaded in steps (on the left) and when loaded continuously (on the right)

RESULTS AND VALIDATION

A MATLAB code was written to analyze the result and compare the readings obtained wirelessly and via cabled data acquisition. The code is given in Appendix C. Two load cases were considered as described in the following two subsections.

Load Case 1 (LC1): Loading in Steps

The first load case involved loading in steps of 2 kips until the maximum limit of 10 kips is reached. The load is then held for approximately 10 minutes. Note that for initial support, the overhead crane held the diaphragm horizontally. Once the load cell indicated 2 kips and the hydraulic jack was in contact with the diaphragm, therefore supporting the diaphragm laterally, the crane support was released. Similarly, the unloading was done in steps of 2 kips until fully unloaded. Figure 31 shows the loading and unloading.

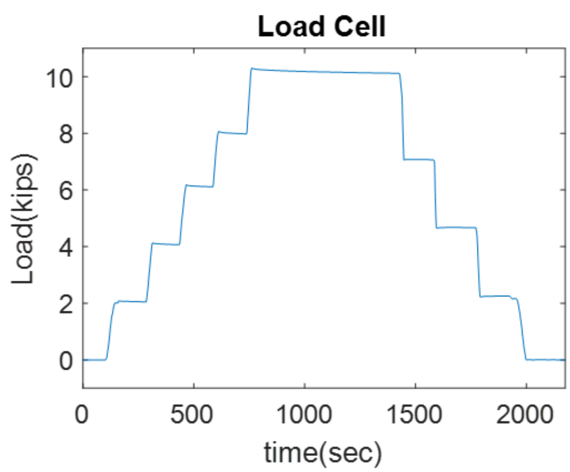


Figure 31. Graph. Variation of the load as a function of time for LC1

The data collection was continuous throughout the loading and unloading stage. The displacement results collected by the string potentiometer are shown in Figure 28, and the maximum displacement can be seen to be around 0.70 inches in the vertical direction, in the direction normal to the plane containing the diaphragm.

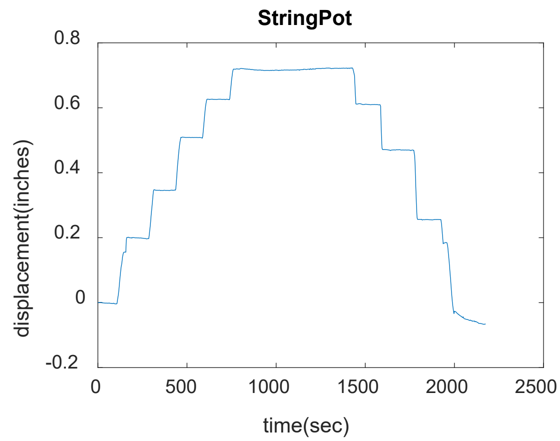


Figure 32. Graph. Variation of the displacement measure by the string potentiometer as a function of time for LC1

Furthermore, the displacements in the two lateral directions were measured during the loading and unloading. Displacement from LVDT2 is shown in Figure 33, where the maximum displacement can be seen to around 0.3 inches.

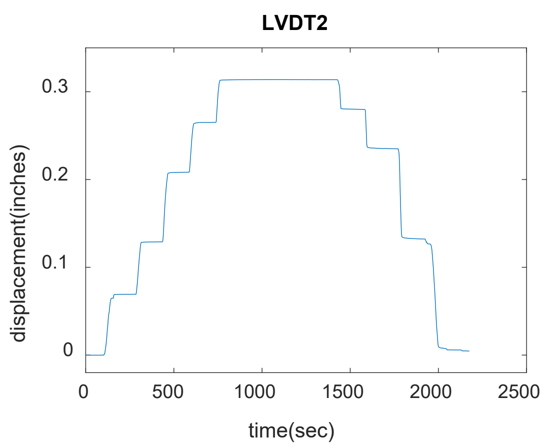


Figure 33. Graph. Variation of the displacement measure by LVDT2 as a function of time for LC1

The results from the adjacent strain gauges were plotted for comparison purposes to ensure that the strain collected through wired NI DAQ and those obtained wirelessly through Martlet agree within a reasonable margin of errors. The overlaying plots for some strain gauge locations are shown in Figure 34 and Figure 35. $M_o$and M_5 are the strains measured at the location shown in Figure 34 and Figure 35, respectively, by Martlet using full bridge strain gauges, and $FSBG_0$ and $QBSG_5$ are the strains measured by NI in a similar location using a full bridge and quarter bridge strain gauge, respectively.

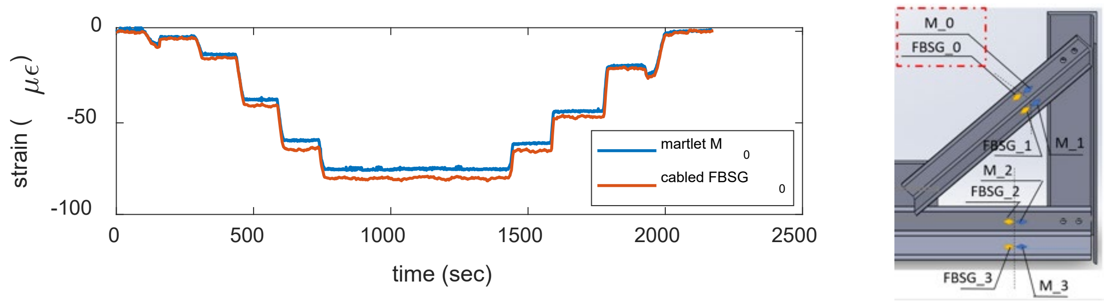


Figure 34. Graph. Plot of the strain as a function of time using Martlet and NI DAQ (left) at locations M_0 and $FBSG_0$ (right) for LC1

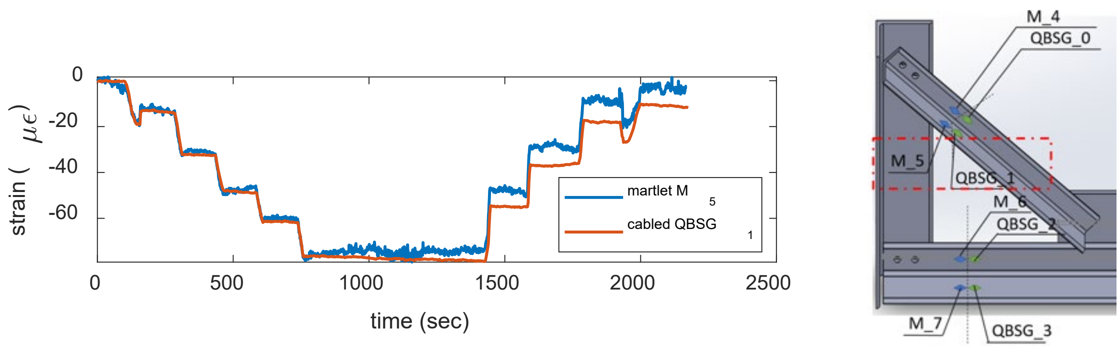


Figure 35. Graph. Plot of the strain as a function of time using Martlet and NI DAQ (left) at locations M_5 and $QBSG_1$ (right) for LC1

The plots that the measured strain by the two different methods of data acquisition agree within 2.8% in the loading phase and 7.8% overall.

Load Case 2 (LC2): Loading Continuously

To test the data acquisition system further, a second loading scenario was also tested. For that purpose, a 2-kip load was applied, at which point the crane supporting the diaphragm horizontally was relieved. After that, the load was increasing continuously until the 10 kips limit load was reached. The diaphragm was held at that loading for a few minutes. Similarly, for unloading, the hydraulic jack was released until the load cell read 2 kips. At this stage, the crane was activated again to avoid any unnecessary stresses to the diaphragm, then fully unloaded and no longer supported by the hydraulic jack and load cell setup. This loading scenario is illustrated in Figure 36.

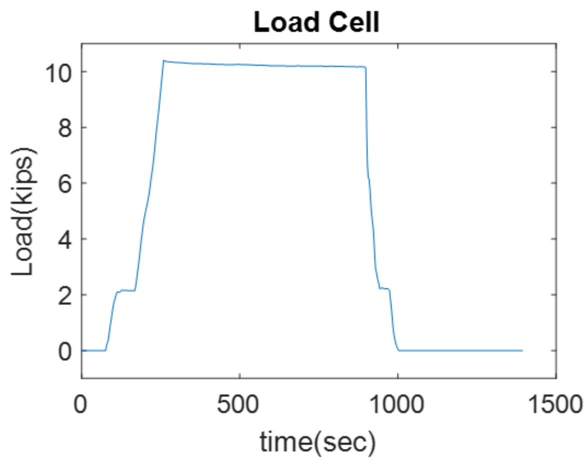


Figure 36. Graph. Variation of the load as a function of time for Load Case 1

Overlaying plots of the load strain obtained from Martlet and NI are provided in Figure 37 and Figure 38 for the same locations presented for LC1. A similar observation can be made by comparing the strains for LC2 using the different data acquisition systems. The plots show that the measured strain by the two different methods of data acquisition agree within 5.1% margin of error for loading and constant regime and 3.6% margin of error overall. These results were deemed satisfactory and, overall, validated the wireless sensing system that will be used for field testing.

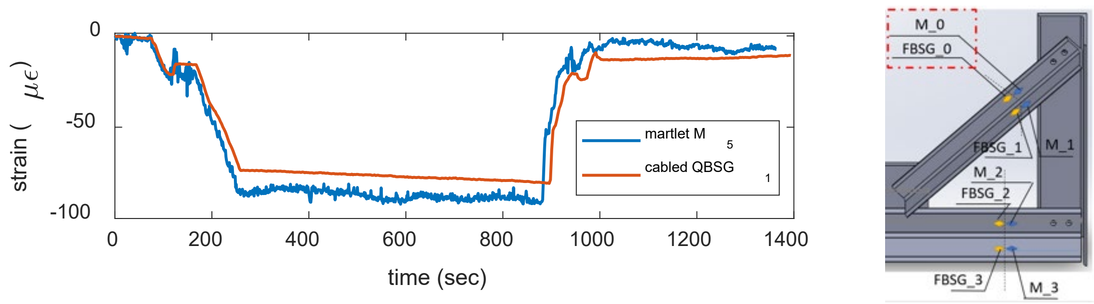


Figure 37. Graph. Plot of the strain as a function of time using Martlet and NI DAQ (left) at locations M_0 and $FBSG_0$ (right) for LC2

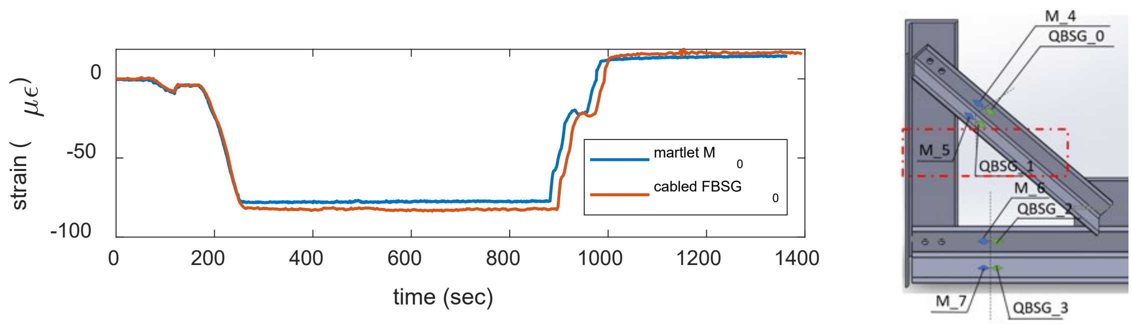


Figure 38. Graph. Plot of the strain as a function of time using Martlet and NI DAQ (left) at locations M_5 and $QBSG_1$ (right) for LC2

CHAPTER 5. BRIDGE MONITORING

The bridge monitoring consisted of two monitorings. The first monitoring effort was conducted as a “dry run” to check the installation processes at the construction site. The second monitoring effort was conducted during the pouring of the concrete deck. The following sections discuss these two efforts.

BRIDGE MONITORING 1

The first monitoring effort that was the “dry run” of the installation was conducted on October 24 and November 11, 2019. It was located at Bridge 11B in Macon I16-I75 Interchange Project and consisted of Span 27RT, as shown in Figure 39 and Figure 40. More specifically, the intermediate diaphragm of the exterior bay of the span, shown in Figure 41, was instrumented. The diaphragm consists of a single chord, specifically a MC18x42.7 structural steel section connected to two plates shown in Figure 42. A photo of Span 27RT is shown in Figure 43.

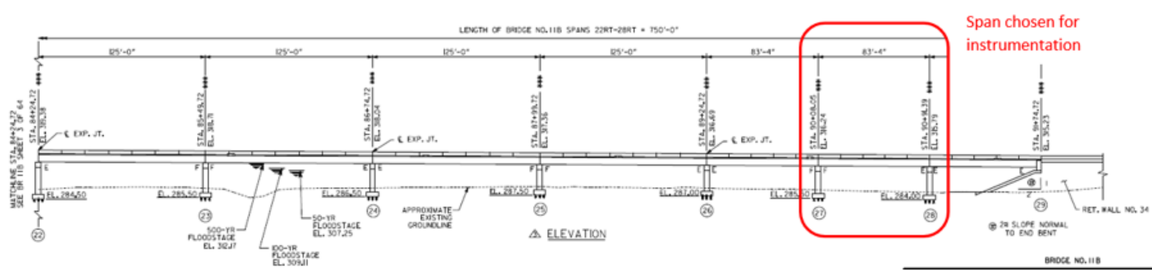


Figure 39. Engineering drawing. Elevation view, bridge Sheet 3 of 64, Bridge 11B plans

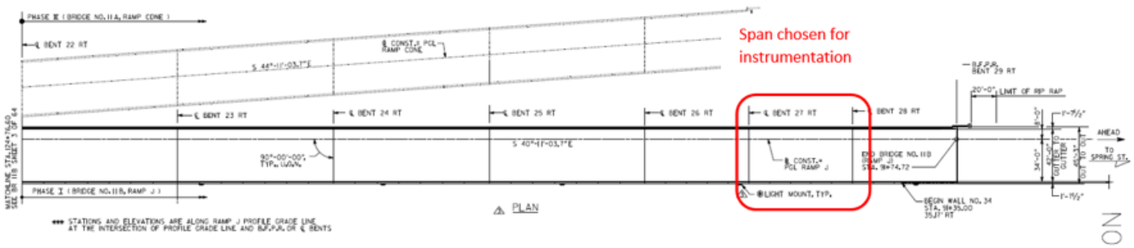


Figure 40. Engineering Drawing. Plan view Span 27RT, Bridge 11B

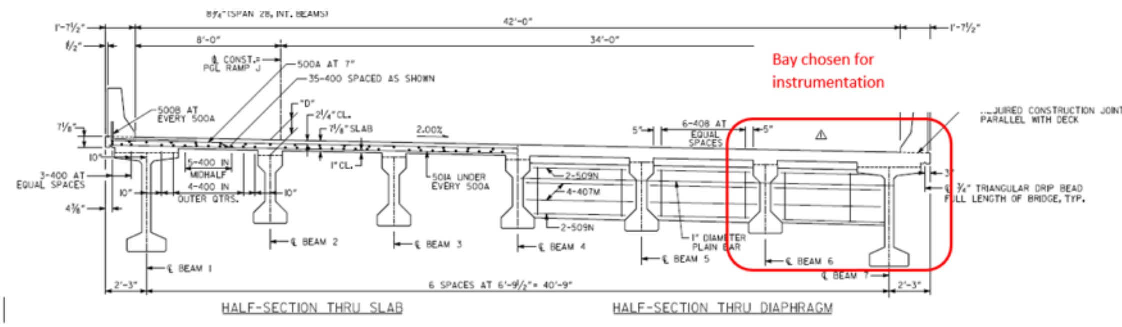


Figure 41. Engineering Drawing. Half-Section Span 27RT, Bridge 11B

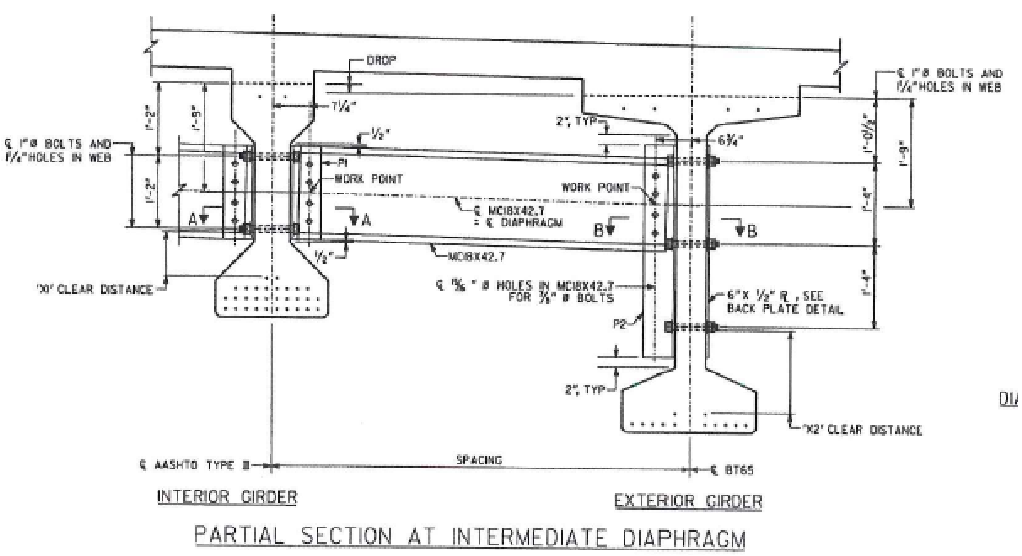


Figure 42. Engineering drawing. Partial section at intermediate diaphragm

Figure 43. Photo. Panoramic picture of Span27RT

Instrumentation

Figure 44 provides the instrumentation layout for the strain gauges and temperature sensors instrumented on the diaphragm. Each strain gauge is labeled “SG,” followed by an arbitrary numeric identifier. Also, temperature sensors are labeled “TS,” followed by an arbitrary numeric identifier. Four strain gauges were installed at the locations shown, in addition to two temperature gauges. Strain gauges were installed 6 inches away from the centerline on each side of the centerline on the inner side of the top and bottom flange. The temperature gauges were fixed to the bottom flange of the steel surface. Note that TS1 was fixed adjacent to SG2, while TS2 was fixed adjacent to SG4. Two Martlet units were used, unit 106 (U106) and unit 128 (U128). Each unit was connected to two strain gauges and one temperature sensor. A summary of the sensors is given in Table 3. Summary of Martlet Units and Sensors.

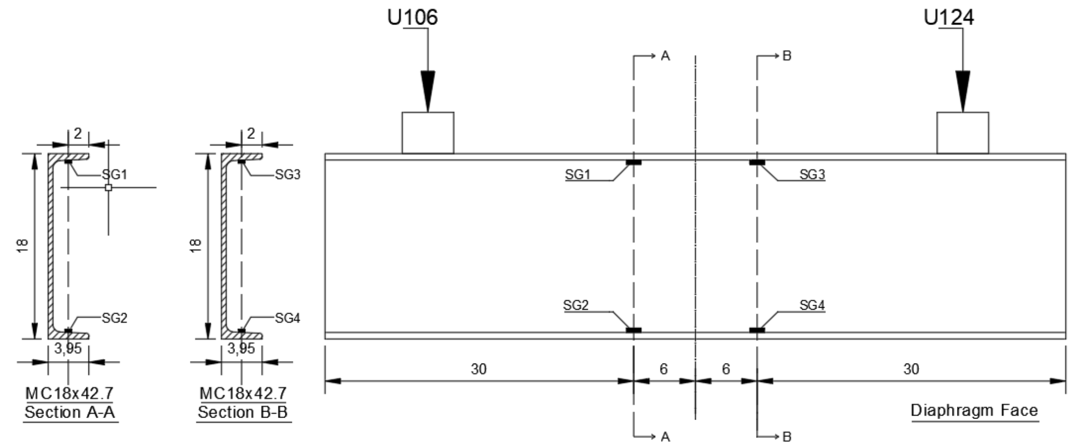


Figure 44. Schematic. Instrumentation layout and sensor numeric identifiers

Table 3. Summary of Martlet Units and Sensors

	CH_0	**CH_1**	**CH_3**
Unit 119	SG1	SG2	TS1
Unit 103	SG3	SG4	TS2
Unit 118	SG5	SG6	TS3
Unit 101	SG7	SG8	TS4

Installation Procedure

To install the sensors, namely the strain gauges and the thermistors, a few keys steps had to be taken to ensure proper installation. First, the planned location for the strain gauges to be instrumented were marked. Next, using an electric belt sander, the corresponding surfaces were sanded down as needed. The surfaces were then thoroughly cleaned using alcohol and a cloth. The locations of the gauges were re-marked as needed. The appropriate epoxy was applied onto one end of the gauges and attached to the surface. To ensure proper bonding, a cutout piece of plexiglass was placed onto the gauges for protection, and clamps were used to apply pressure. The clamps and plexiglass were then removed once proper bonding had been ensured. Next, the temperature sensors were secured onto the steel members at the appropriate locations. Antennas were then connected to the wireless sensing units and placed onto the steel members such that it maintained line of sight with the base station during data collection. Furthermore, all the sensors were connected to the appropriate sensor boards. The wireless sensing units were then placed in waterproof boxes, which were then screwed shut and securely attached onto the steel diaphragms. Finally, the necessary waterproofing was applied onto the strain gauges to ensure longevity during different weather conditions. Figure 45 illustrates some steps of the installation procedure. Note that, following data collection, all units were disassembled and taken back to the laboratory for inspection.

Figure 45. Photo. Collection of pictures depicting strain gauge installation process

Data Collection

For the data collection, the laptop, base station, and antenna were set up below the bridge. Data was continuously sent wirelessly and plotted in MATLAB in addition to being saved to the secure digital (SD) card to ensure continuous successful receipt of the data. The data acquisition setup worked as intended and was deemed adequate for future data collection.

Figure 46. Photo. Setup for data acquisition

BRIDGE MONITORING 2

The second monitoring effort monitored Span 14 of Bridge 11B of the I-16/I-75 Interchange project, shown in Figure 47 through Figure 51. The diaphragm was instrumented and monitored during the concrete deck pours to determine the strain induced in the steel diaphragms due to the weight of the concrete and other equipment during the pours. This span consists of nine 125-foot PSC girders and eight intermediate k-frame steel diaphragms located midspan, shown in Figure 52.

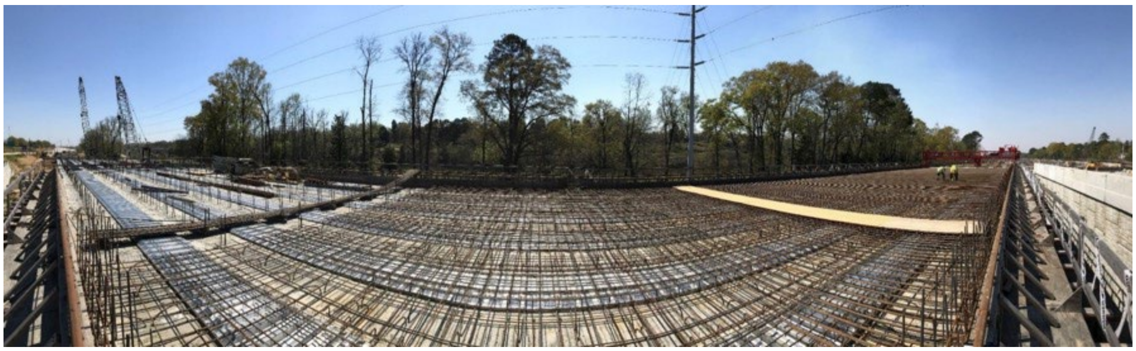


Figure 47. Photo. Steel reinforcement in deck prior to pour

Figure 48. Photo. End of span prior to concrete deck pour

Figure 49. Photo. Panoramic photo of span prior to deck pour

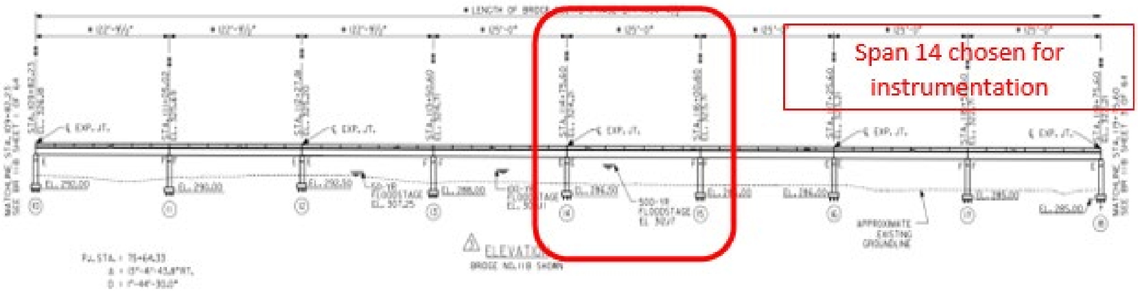


Figure 50. Drawings. Elevation view, Bridge 11B

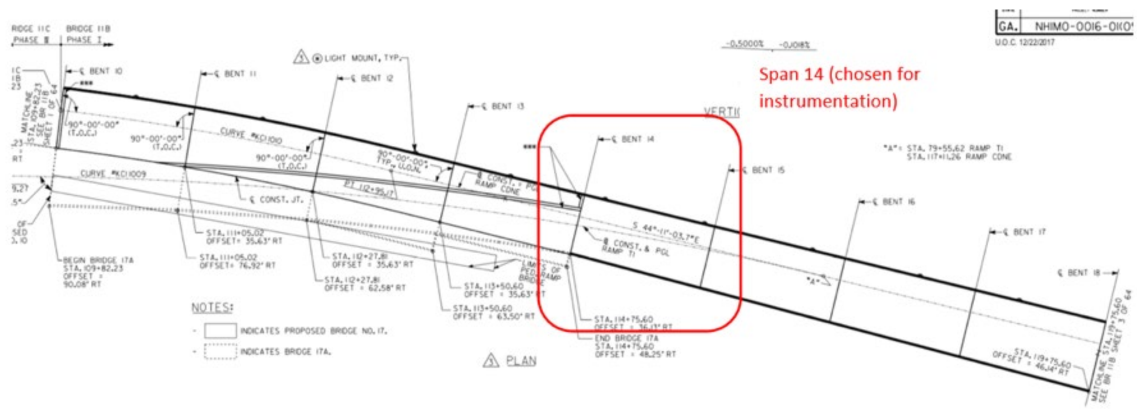


Figure 51. Drawings. Plan view, Bridge 11B

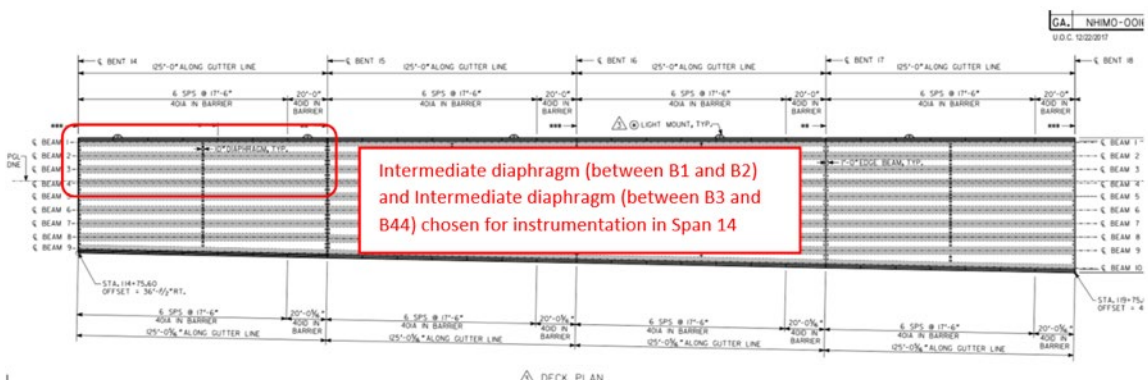


Figure 52. Drawings. Deck plan of Span 14, Bridge 11B

Two bays with steel k-frame diaphragms of the mentioned span were chosen for instrumentation, shown in Figure 53. More specifically, an intermediate diaphragm of the exterior bay of the span and an intermediate diaphragm of the interior bay of the span, were instrumented. The diaphragm consists of an L5x5x0.5 and two diagonal L3.5x3.5x0.5 structural steel sections connected to two plates shown in Figure 54.

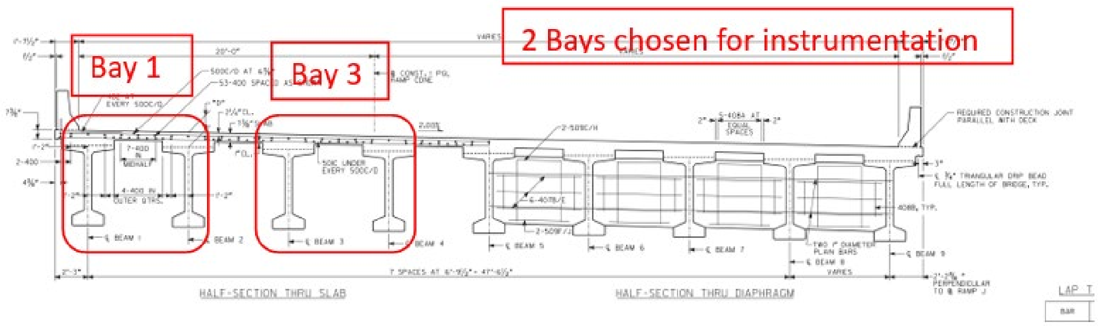


Figure 53. Drawings. Four Half-Section of Span 14, Bridge 11B

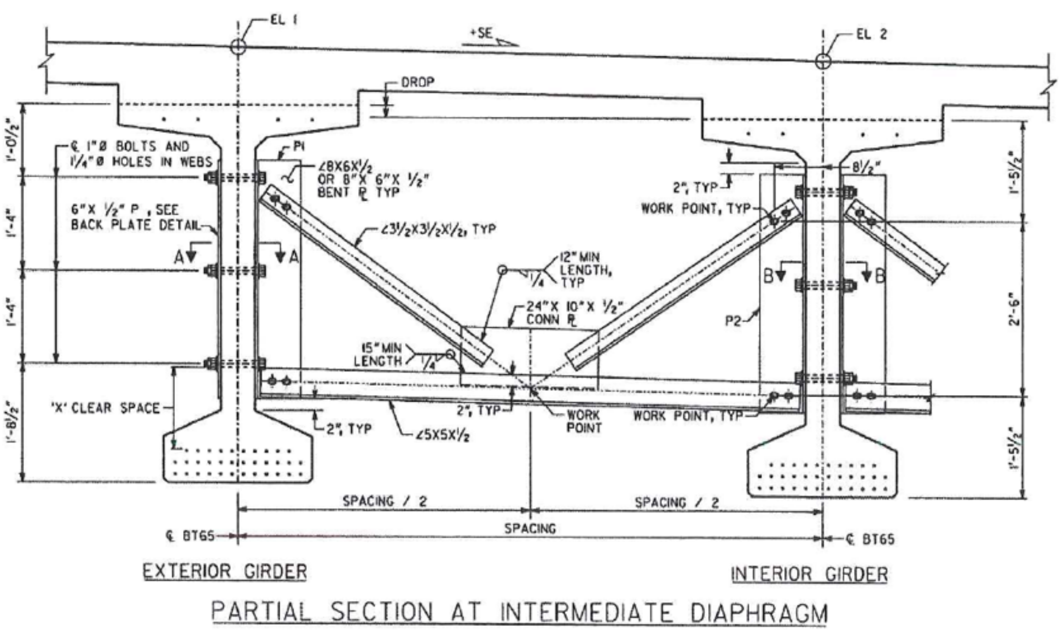


Figure 54. Engineering Drawings. K-frame steel diaphragm

Figure 55 provides the instrumentation layout for the strain gauges and temperature sensors to be instrumented on the diaphragm. Each strain gauge is labeled “SG” followed by an arbitrary numeric identifier. Also, temperature sensors are labeled “TS” followed by an arbitrary numeric identifier. Eight strain gauges per diaphragm were installed at the locations shown, in addition to four temperature gauges per diaphragm for total of 16 strain gauges and 8 temperature sensors. Strain gauges were installed 20 inches from the exterior end of all members, at the locations on the cross sections shown in the left of Figure 55. The temperature gauges were fixed to the steel surface. Four Martlet units were used per diaphragm for a total of eight Martlet units. Each unit was connected to two strain gauges and one temperature sensor. The units were programmed with the latest version of the software code prior to installation. Details of the connections are shown in Table 4 and Table 5.

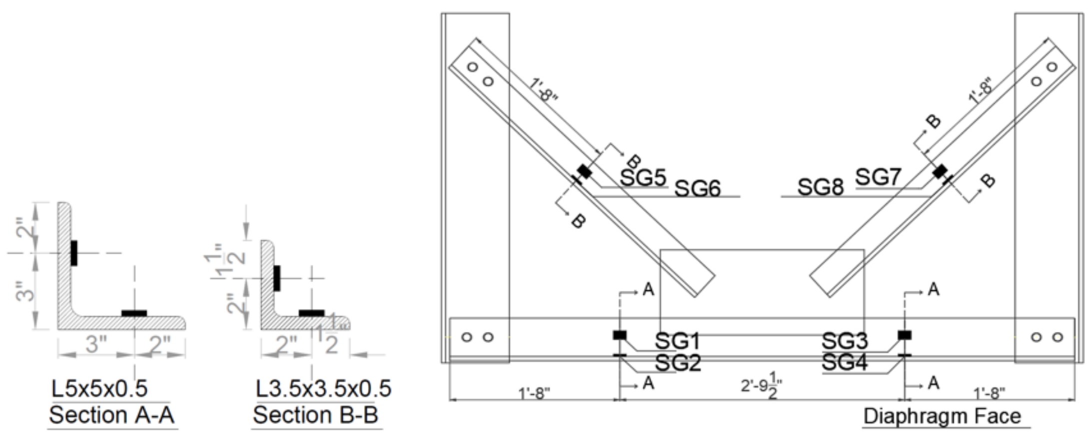


Figure 55. Schematic. Instrumentation layout and sensor numeric identifiers

Table 4. Martlet Units and Sensors used for External Diaphragm

	CH_0	CH_1	CH_3
Unit 128	SG1	SG2	TS1
Unit 116	SG3	SG4	TS2
Unit 102	SG5	SG6	TS3
Unit 100	SG7	SG8	TS4

Table 5. of Martlet Units and Sensors used for Internal diaphragm

	CH_0	CH_1	CH_3
Unit 119	SG1	SG2	TS1
Unit 125	SG3	SG4	TS2
Unit 118	SG5	SG6	TS3
Unit 101	SG7	SG8	TS4

The installation process was like that described for Span 27RT and is illustrated in Figure 56 through Figure 59. First, the surfaces were sanded and cleaned and then the gauges were bonded to the surface. Next, the gauges were weatherproofed. Finally, the wireless units were connected.

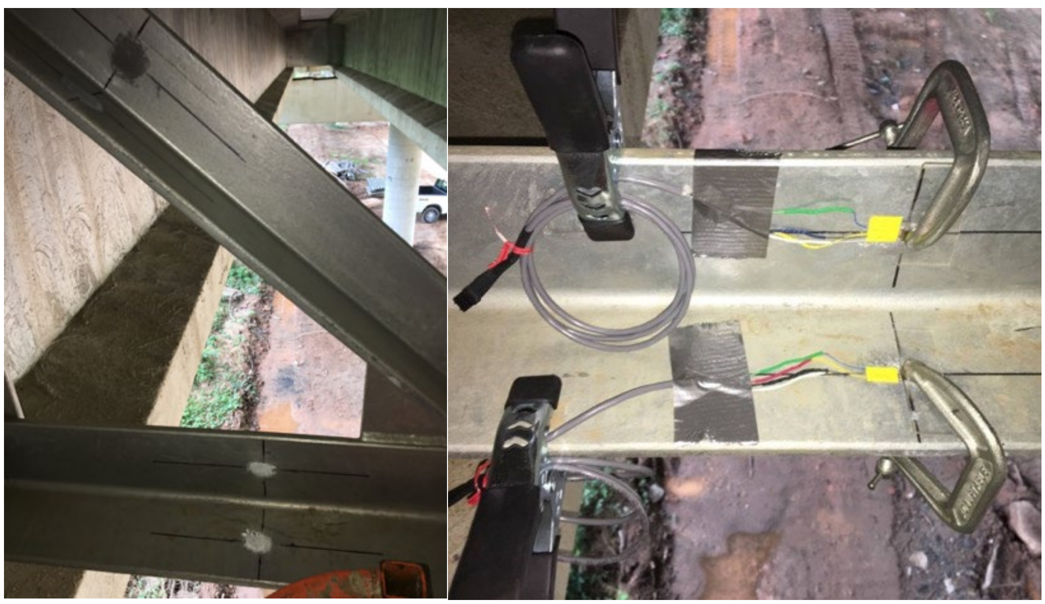


Figure 56. Photo. Cleaning and sanding of the surface (left), bonding of strain gauges (right)

Figure 57. Photo. Strain gauges after bonding to surface

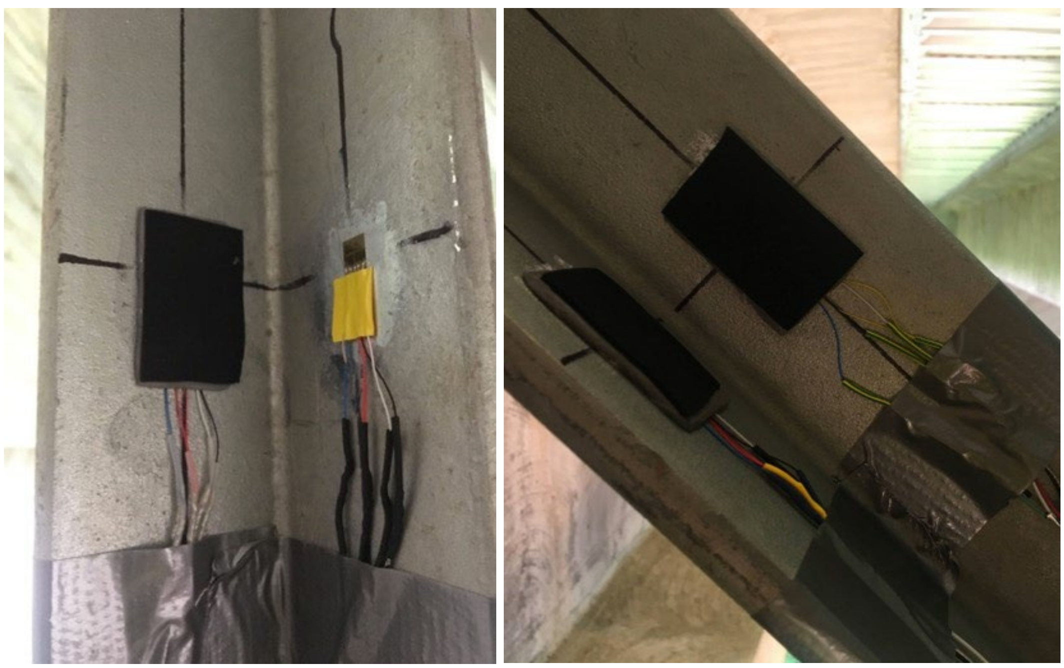


Figure 58. Photo. Weatherproofing of strain gauges

Figure 59. Photo. Final product of strain gauges installation and connection to wireless sensing units for Bay 1 (left) and Bay 3 (right)

Following the installation, the data acquisition systems were tested by collecting ambient data to ensure proper communication and transfer of data between the wireless sensing units and the base station. The batteries were collected after installation and taken to the laboratory to ensure they were fully charged for the day of the pour.

The deck was poured on August 26, 2020, at approximately 4:00 a.m. The trucks just prior to the pour time are shown in Figure 60. The fully charged batteries were reconnected to the units, which were turned on and ready to collect data at the beginning of the concrete pour.

Figure 60. Photo. Deck pour on August 26, 2020

The base station (Figure 61), laptop, and antenna were setup under the bridge, maintaining line of site with the wireless sensing units. Data was continuously collected during the concrete pour and was uninterruptedly sent wirelessly to the base station over the entire duration of the data acquisition. The concrete pour ended around 8:00 a.m. ET. Data collection stopped a few hours after the concrete pouring was completed. In addition to data collection, two time-lapse cameras were set up on both sides of the bridge to capture the events on top of the of the bridge, shown in Figure 62. The footage was reexamined in conjunction with the collected strain data.

Figure 61. Photo. Base station setup during data collection

Figure 62. Photo. Time-lapse camera footage on both sides of the bridge

Data Analysis

The raw data, which was collected in volts, was appropriately converted to the physical quantity of strain and temperature. Moreover, a smoothing filter was applied to better visualize the trend of the collected data. More specifically, the "rloess" function, a more robust version of the "loess" filter assigning lower weights to outliers in the regression, was used for that purpose. This filter performs local regression using weighted linear least squared and a second-degree polynomial model to provide a filtered version of the raw data and reduce the noise, as shown in Figure 63.

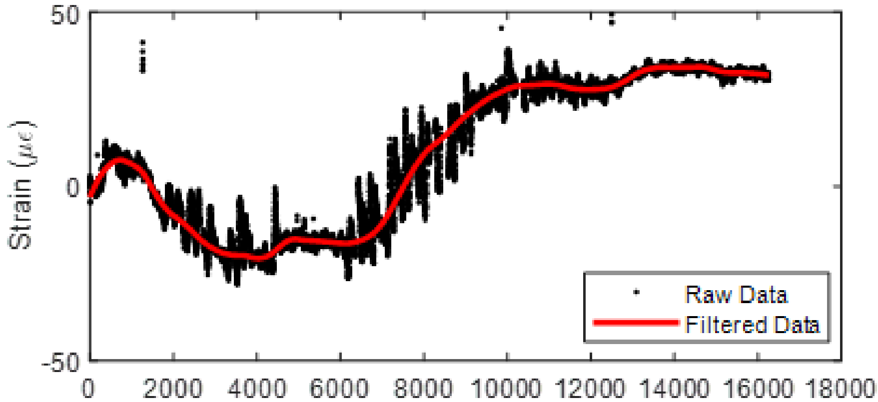


Figure 63. Graph. Raw data (black) versus filtered data (Red)

The filtered data from the concrete deck pouring process is summarized in Figure 64 through Figure 67. Unfiltered data can be found in Appendix D. Note that three strain gauges were damaged and did not collect any meaningful data. The strain entries for these gauges are represented by an 'X' in the table.

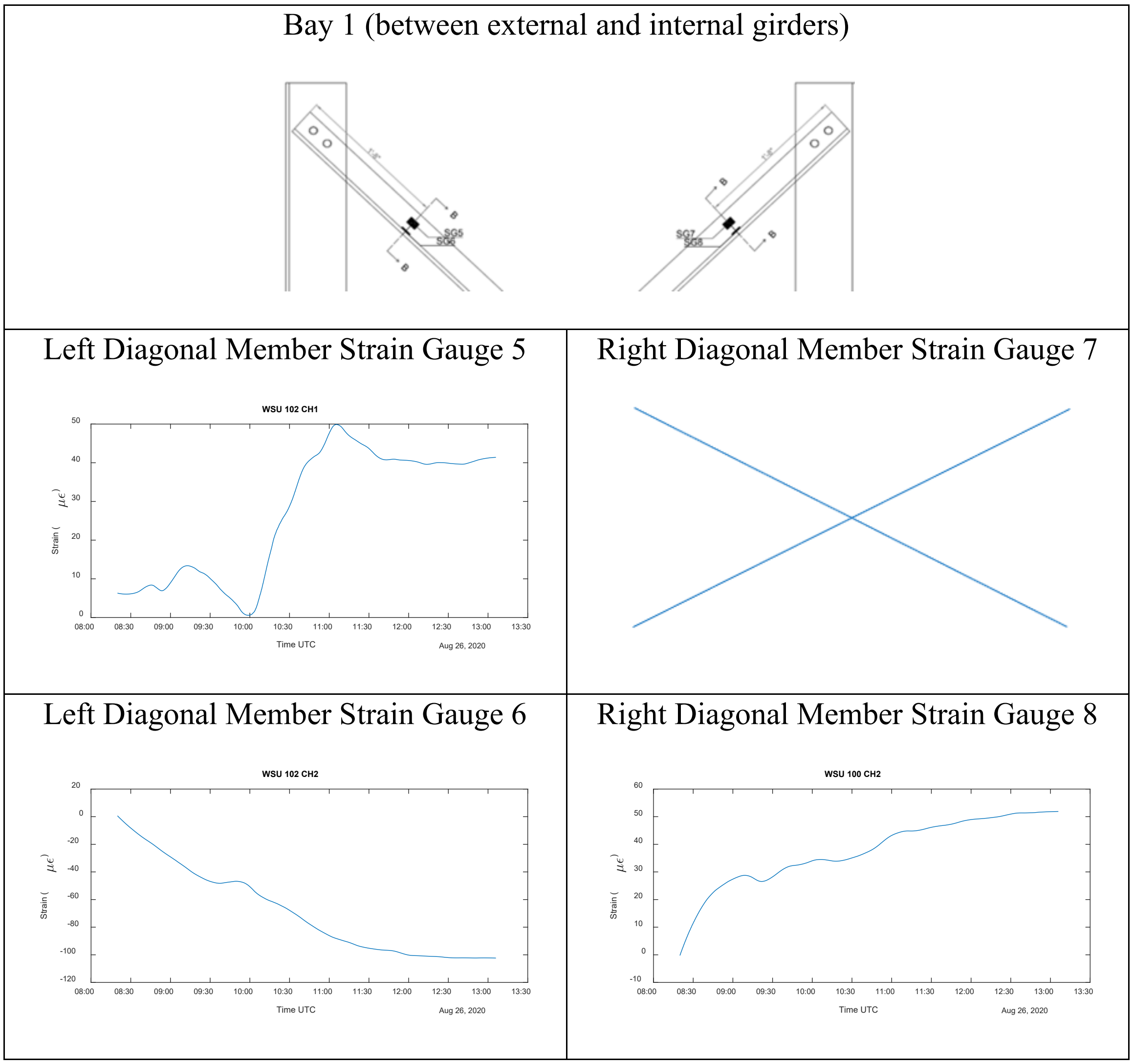
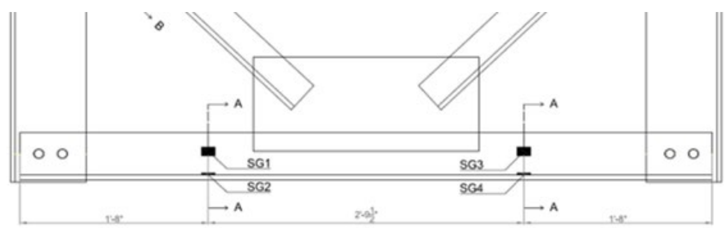
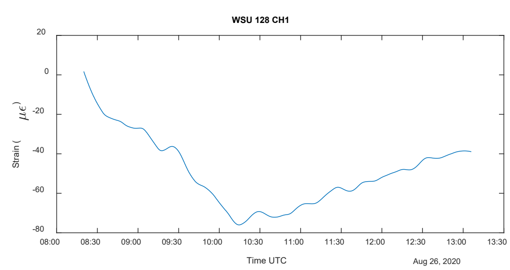


Figure 64. Data. Strain gauge data from top of Bay 1

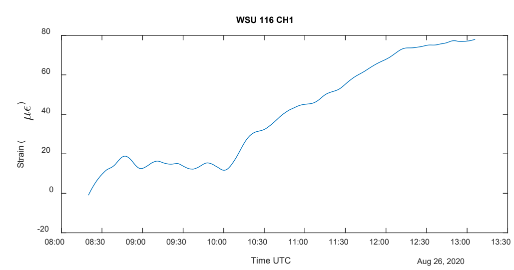
Bay 1 (between external and internal girders)



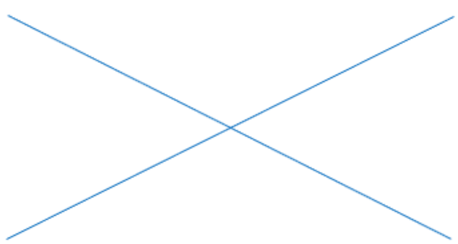
Bottom Member (Left) Strain Gauge 1



Bottom Member (Right) Strain Gauge 3



Bottom Member (Left) Strain Gauge 2



Bottom Member (Right) Strain Gauge 4

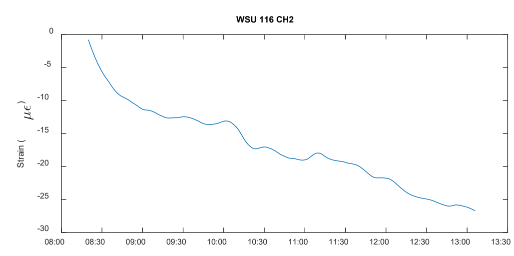
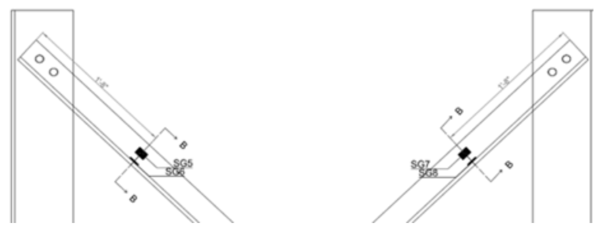
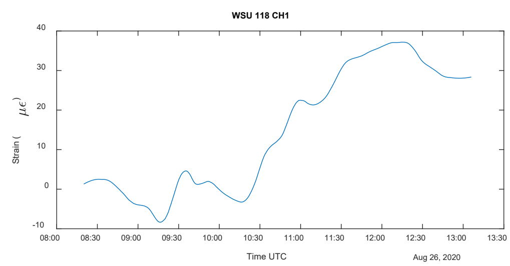


Figure 65. Data. Strain gauge data from bottom of Bay 1

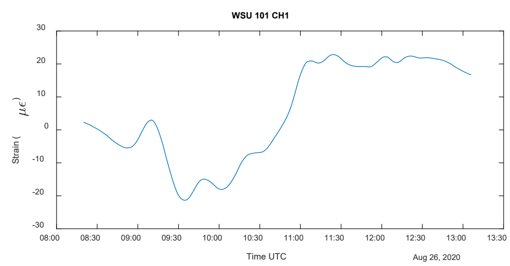
Bay 3 (between two internal diaphragms)



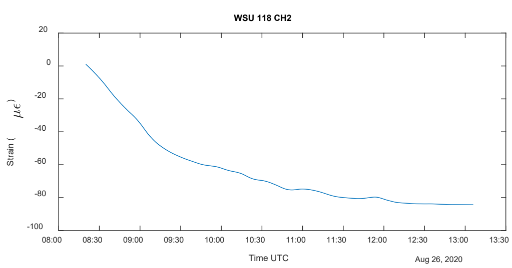
Left Diagonal Member Strain Gauge 5



Right Diagonal Member Strain Gauge 7



Left Diagonal Member Strain Gauge 6



Right Diagonal Member Strain Gauge 8

Figure 66. Data. Strain gauge data from top of Bay 3

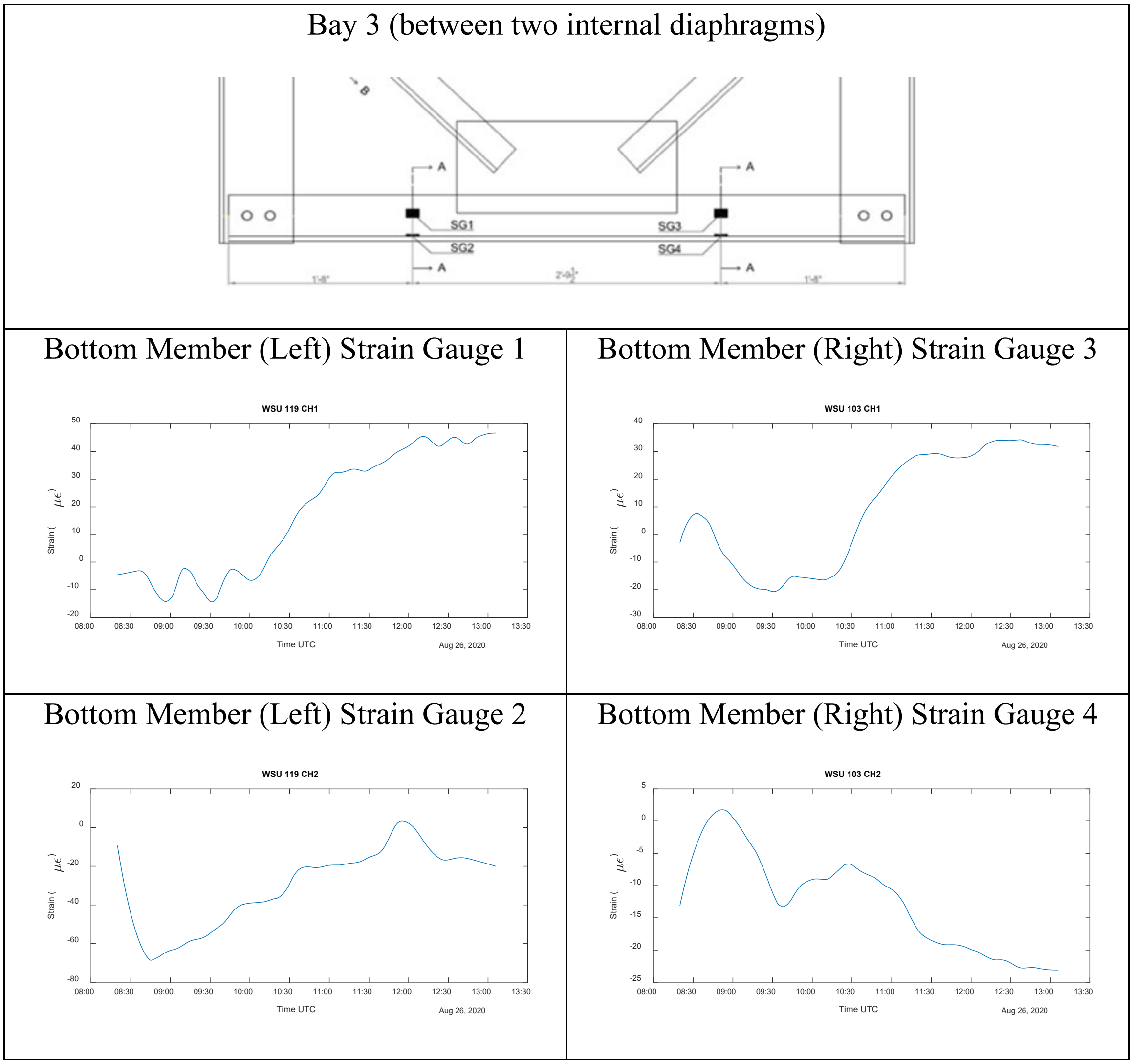


Figure 67. Data. Strain gauge data from bottom of Bay 3

CHAPTER 6. FINITE ELEMENT MODELS

To better understand how the loads are distributed within the diaphragm elements, three models were created with three different software: a SAP2000 Model, a CSIBridge model, and an Abaqus model. This chapter summarizes the results from the models and provides comparisons with the monitoring effort.

SAP2000 MODEL

A simplified model of the k-frame diaphragm of Span 14 of Bridge 11B was constructed using the commercial finite element program SAP2000.[(23)] The purpose behind the model was to provide a preliminary analysis of the internal forces and moments in the diaphragm when subjected to concentrated wind forces. The model was also used to reproduce the calculations provided by GDOT using the finite-element model software RISA.

The SAP model consisted of the structural steel angle members, where the effective lengths of the members were taken from the innermost slotted bolt holes. The effective lengths are represented by the red lines in Figure 68. The support conditions were modeled as pin supports at one end of the diaphragm members and roller supports at the opposite end. Wind load calculations for this specific span were performed, and the load was applied to the model as a concentrated force at one end of the top diagonal member and the bottom chord member. A linear analysis was run with the applied concentrated forces. As a result, the reactions at the supports were calculated and are shown in Figure

69. Additionally, the resulting stresses and internal forces in each member were obtained (Figure 70). The values obtained matched those provided by GDOT.

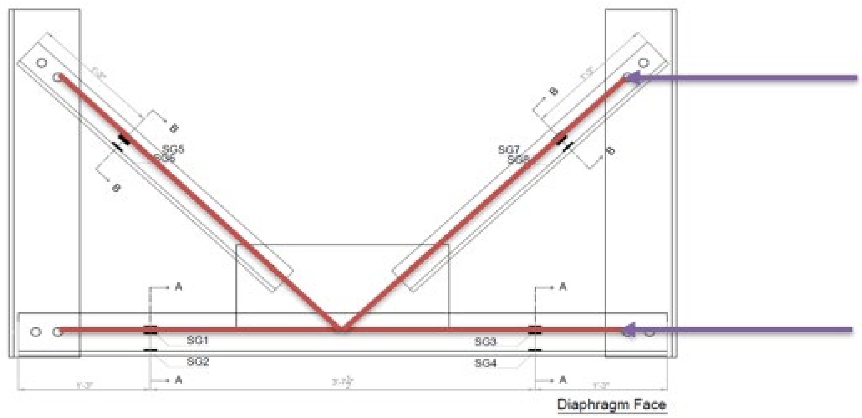


Figure 68. Schematic. Effective length used in SAP2000 model

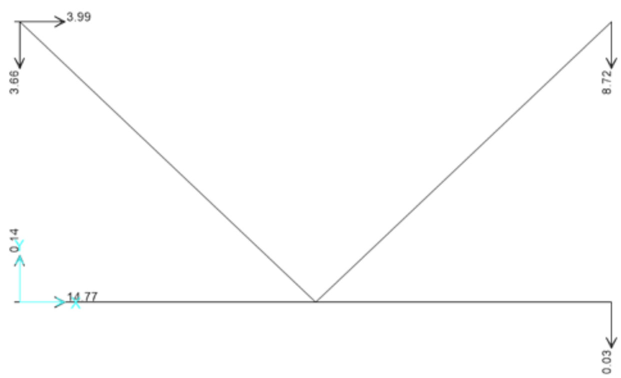


Figure 69. Schematics. SAP2000 K-frame diaphragm reaction forces

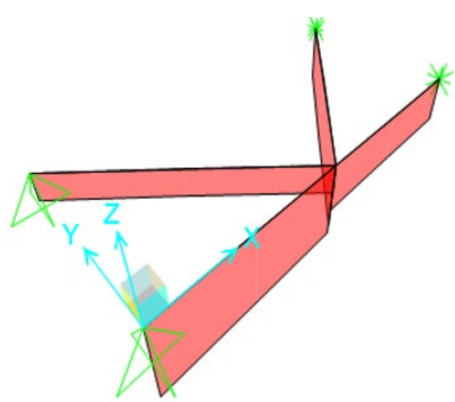


Figure 70. Schematics. SAP2000 analysis axial forces

CSIBRIDGE MODEL

The commercial finite element software CSIBridge was used to construct an initial model of Span 14 of Bridge11B of the I-16 I-75 Interchange that was to be instrumented.[23] This model consisted of the prestressed reinforced concrete girders, the concrete end diaphragms, and the intermediate steel diaphragms that are the focus of this research. These elements are shown in Figure 71, Figure 72, and Figure 73.

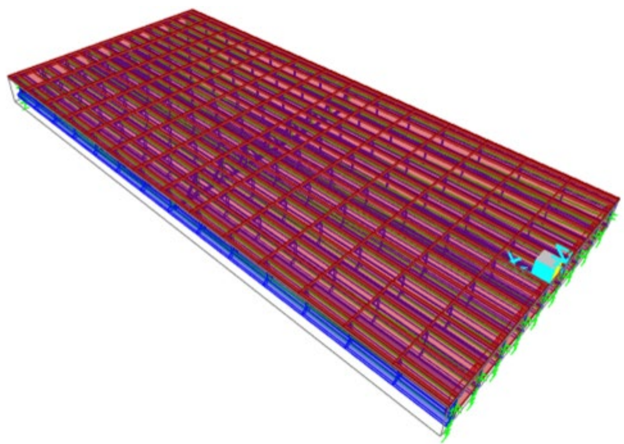


Figure 71. Model. CSIBridge model of Span 14 of Bridge11B of the I-16 I-75 Interchange project with prestressed girders

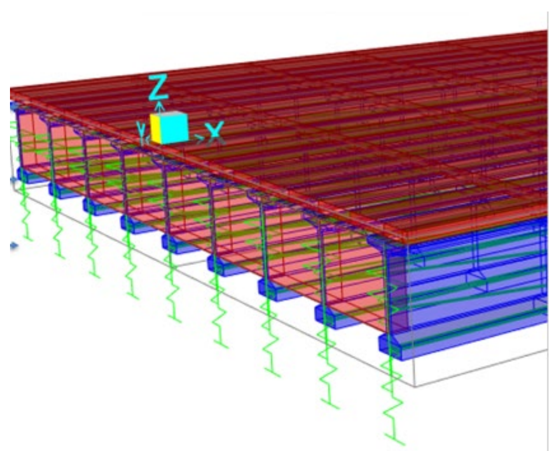


Figure 72. Model. Concrete end diaphragms and supports in CSIBridge model

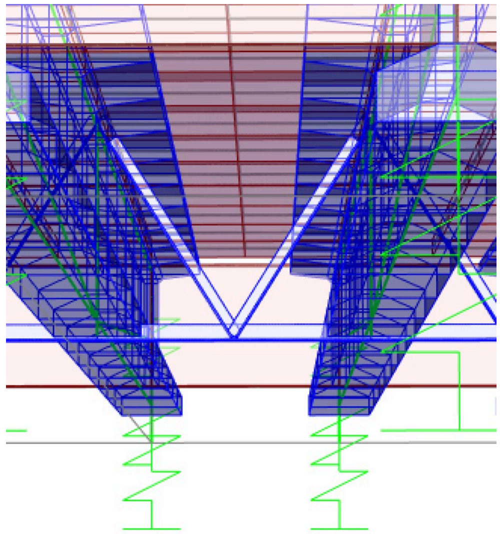


Figure 73. Model. K-frame intermediate steel diaphragms in CSIBridge model

The appropriate member sections and constitutive properties obtained from the provided drawing were used to model the intermediate k-frame diaphragms as well as the reinforced concrete Bulb-Tee girders and the prestressed tendons, shown in Figure 74 and Figure 75. The fixed-expansion support was used to model the end of the spans, as indicated in the drawings in Figure 76.

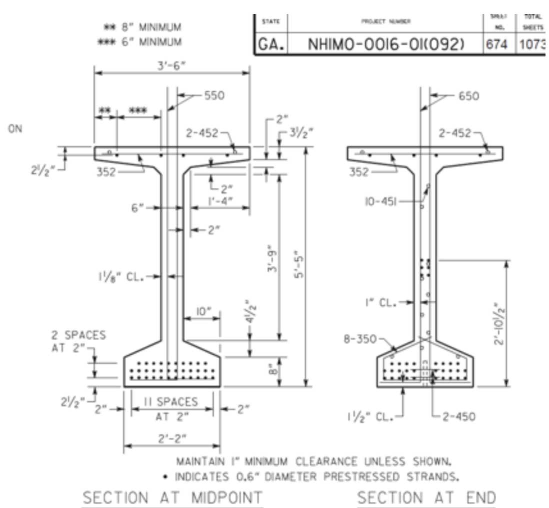


Figure 74. Engineering Drawing. Bulb-Tee section at midpoint and end

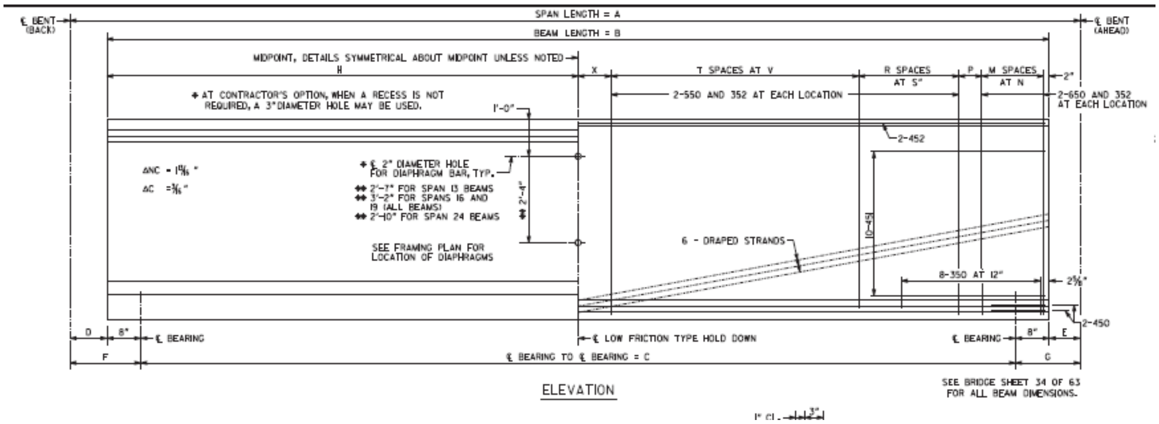


Figure 75. Drawing. Prestressed concrete girder tendons

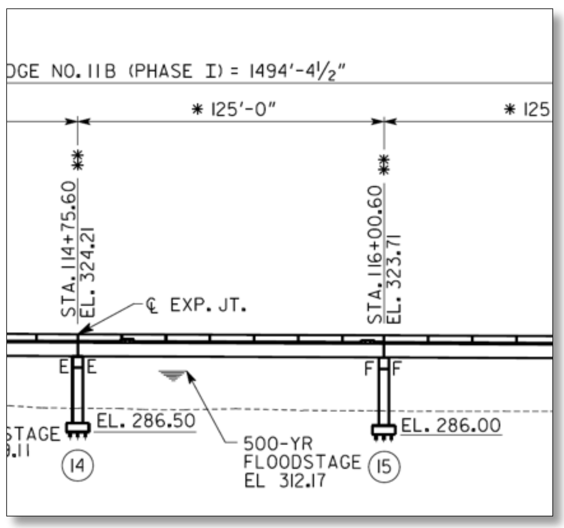


Figure 76. Drawing. Fixed-expansion end supports of Span 14

The tendons were modeled as object elements, using the Bridge Tendon Wizard in CSIBridge. The material property was defined appropriately as A416 Grade 27 steel. The tendon area, load, and layout were adequately calculated and modeled based on the information provided in the shop drawings provided by GDOT. The elevation, plan, and section drawings of the final bridge tendon layout display are shown in Figure 77. Figure 78 shows the modeled tendon objects in green for each of the Bulb-Tee reinforced concrete beams.

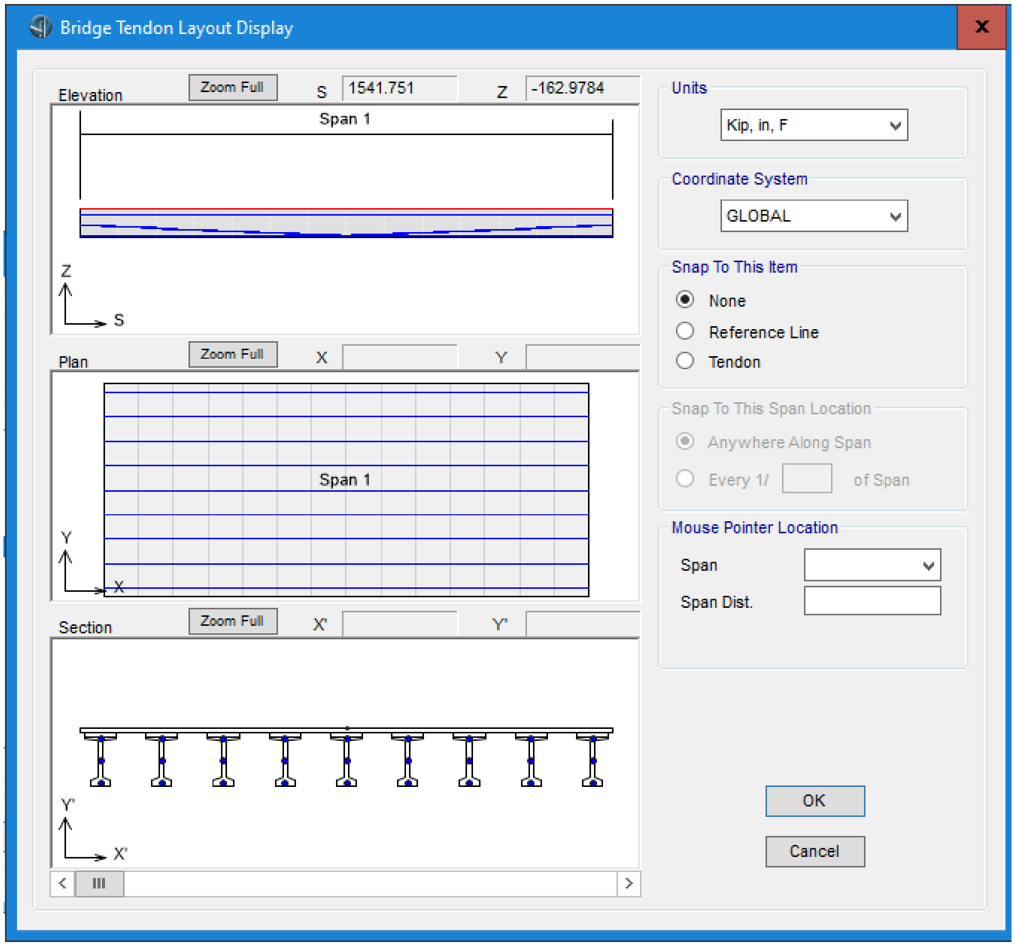


Figure 77. Interface. Elevation, plan, and section drawings of the final bridge tendon layout display

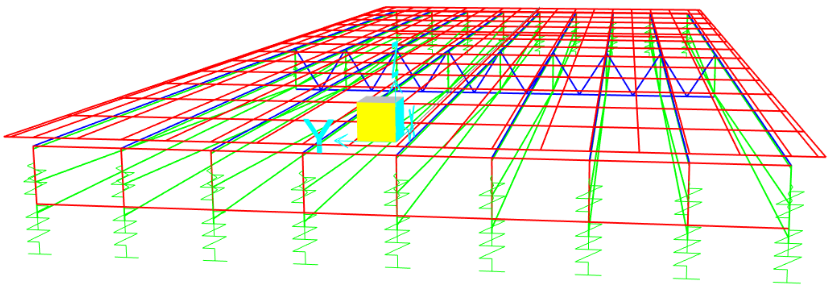


Figure 78. Model. Model tendon objects (in green)

An investigation of different model variables was performed to determine the impact of these variables on the model. Variables included end supports (abutments and bearing properties), diaphragm frame joint offset, tendons modeling, and boundary conditions for the diaphragm members. The initial model was reviewed and updated based on the study findings. The major changes to the model are delineated in what follows.

The boundary conditions of the diaphragms were examined. CSIBridge allows the user to model steel intermediate diaphragms at the desired location and with the desired sectional properties in reinforced concrete girder bridges. By default, CSIBridge releases moments at both ends and torsion at one end of the members of the diaphragm when modeling a k-frame steel diaphragm in a concrete girder bridge. Investigation of the internal forces of the members of the diaphragms under different loading conditions, namely dead load and staged construction, showed that this method did not provide adequate and meaningful results. Therefore, the releases were deemed inadequate and had to be updated for better and more representative results. Consequently, rotational springs were added at the diagonal and bottom chord frame diaphragms ends with some stiffness, shown in Figure 79, and the analysis was rerun to show improved results.

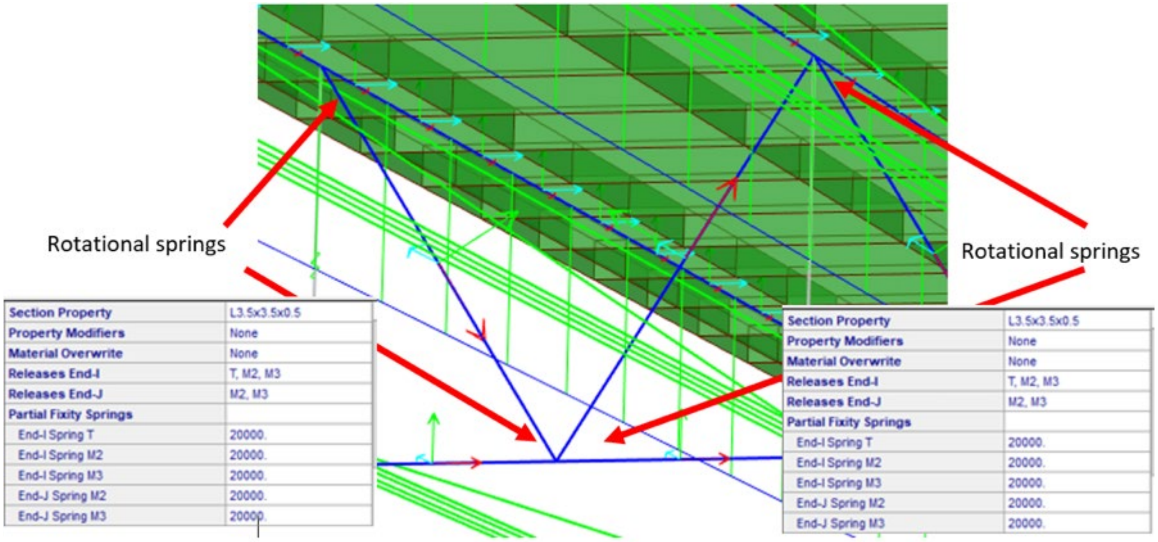


Figure 79. Model. Changes to end releases of steel diaphragms in CSIBridge

The end supports of the span were modeled as abutment links, with specified values for substructure location elevation as well as bearing assignment elevation at layout line. According to CSIBridge documentation, *Substructure Location, Elevation (Global Z)* is the bearing seat elevation, or the elevation at the top of the bent cap or abutment cap; and *Bearing Assignment, Elevation at Layout Line (Global Z)* is the elevation at the bearing action point. Preliminary values were obtained from the abutment section drawings provided by GDOT (Figure 80). The bearing and substructure elevation in CSIBridge, with values, is given in Figure 81.

Analysis of the model was performed for different values of substructure location elevation as well as bearing assignment elevation and lead to negligible impact on the analysis results, and hence this variable was deemed to have little to no significance on the analysis.

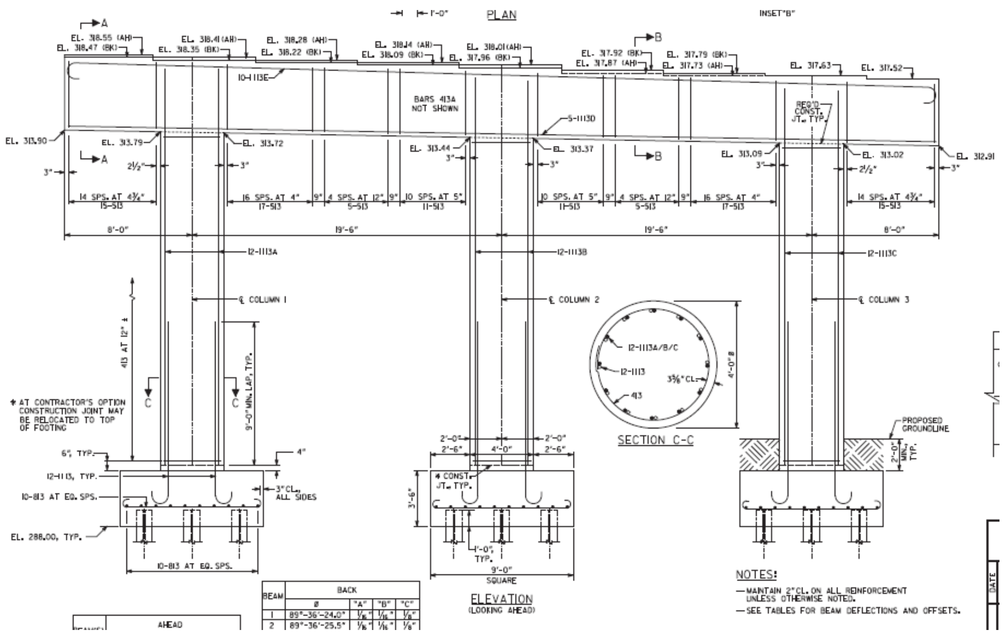


Figure 80. Drawing. Abutment drawings for Span 14 of Bridge 11B

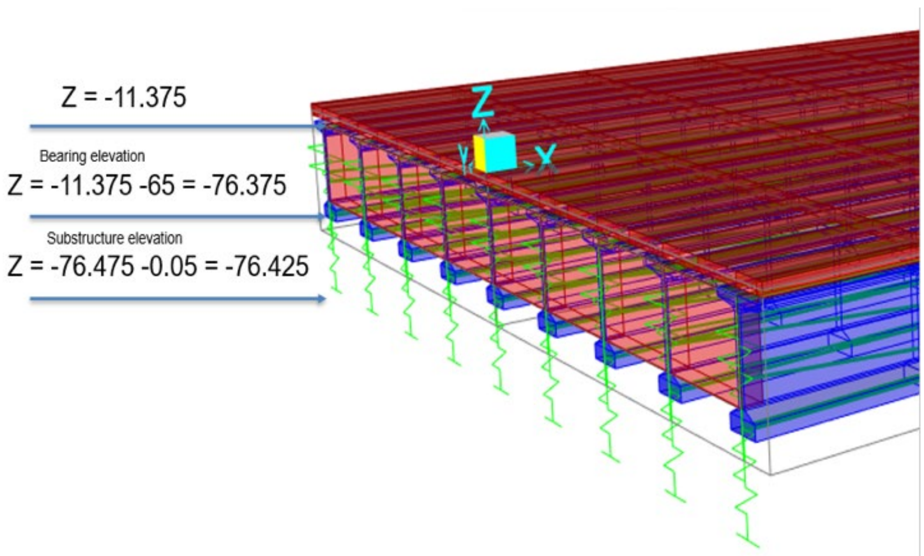


Figure 81. Model. Bearing and substructure elevation in CSIBridge

Another important modification to the steel diaphragms modeled in CSIBridge was to add frame joint offsets to the diagonal members to better model the diaphragms. Examining the drawings provided by GDOT suggests that the diaphragms are connected to a member at a certain distance from the top of the beam (Figure 82). Consequently, frame joint offsets of cardinal points were added to the diagonal members of the diaphragm (Figure 83), to better model the in-situ design of the diaphragms. The updated model was then used to run a multitude of tests for wind load analysis as well as nonlinear staged construction analysis. The next section describes the methodology and the subsequent results.

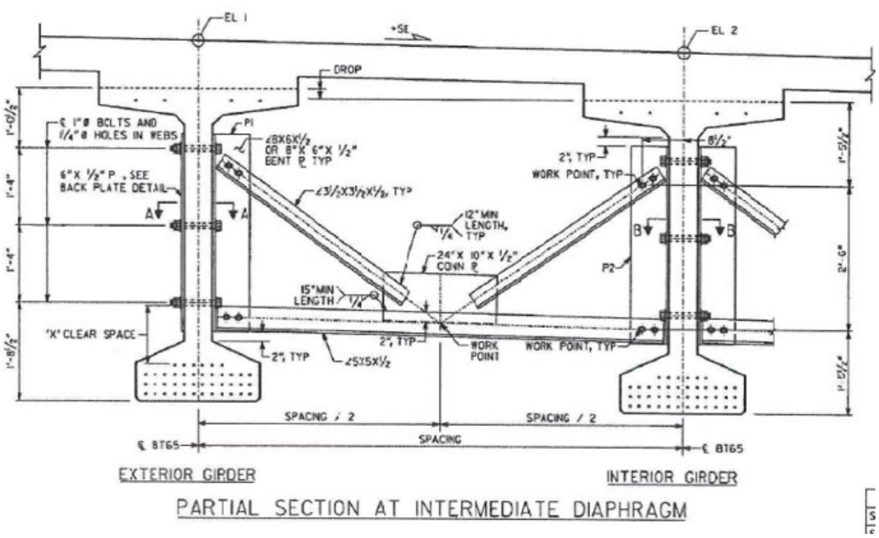


Figure 82. Drawing. Partial section at intermediate diaphragm of Span 14 of Bridge 11B

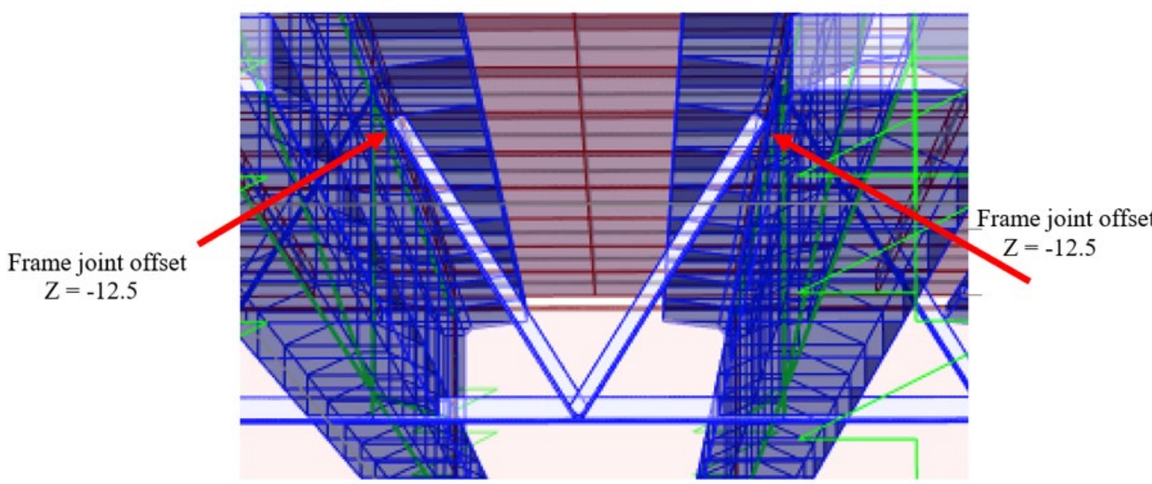


Figure 83. Model. Frame joint offset location for diagonal members of the diaphragm

Wind Load Analysis

A wind load pattern was defined in CSIBridge using an AASHTO2018 auto lateral load patten. An automatic AASHTO 2018 lateral wind load pattern was created with the aim of running the analysis and comparing the stresses in the members of the diaphragms with those obtained in the previous section. For the defined automatic load pattern, the wind load is calculated on the substructure, superstructure, and on live load if present. The defined parameters are specified according to the code chosen, and the wind forces are described as function of the exposed areas and the height. A multistep linear static load case analysis is automatically defined for the AAHSTO 2018 automatic wind load pattern. For the analysis, the wind load is applied at a multitude of different angles to the transverse direction of the bridge. Consequently, the different angles are analyzed as a multistep linear load case. According to the CSIBridge documentation, multistepped load patterns represent several separate and independent loading patterns applied in sequence. Multistepped load patterns can be applied in a multistep static load case, which performs a series of independent linear analysis of the defined load patterns. The analysis, therefore, resulted in six steps, with each step representing an independent linear analysis. The subsequent internal forces and strains in the diaphragms members were examined. Examples of the output is given in Figure 84 and Figure 85 for stress in the 1-1 direction. Additional results are provided in the Comparisons section at the end of this chapter.

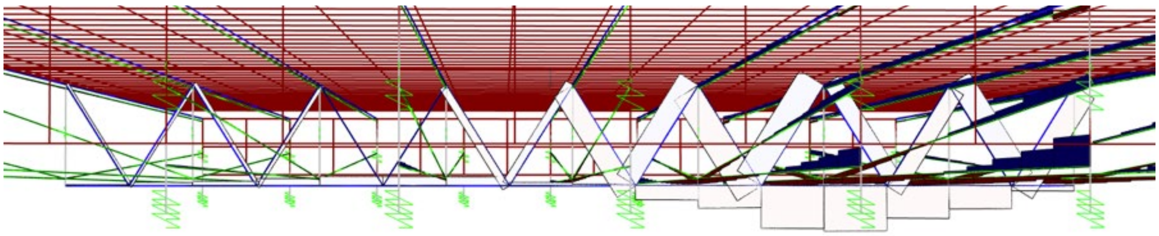


Figure 84. Model. Stress S11 in elements from step 1 of the multistep linear wind load analysis

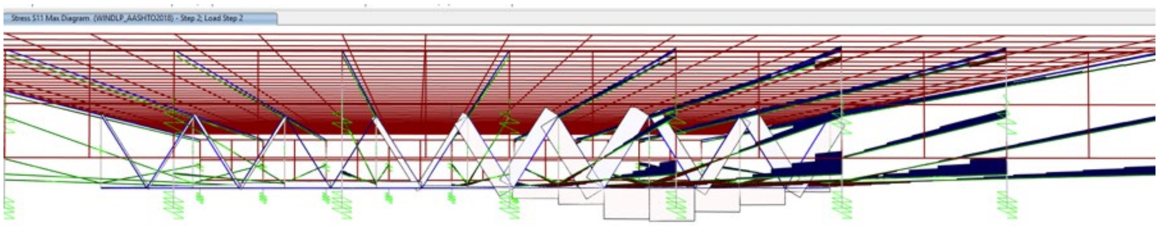


Figure 85. Model. Stress S11 in elements from step 2 of the multistep linear wind load analysis

Staged Construction Analysis

A nonlinear staged construction analysis was performed to model the concrete deck pouring process. This type of analysis allows the user to define multiple stages, with a sequence of operations for each stage. Each operation can include different object types, which can be added and removed as needed to mimic the construction process. Eight stages were defined in the concrete pouring load case. Guides for the top slab are defined in the first stage of the concrete pouring load case. Defining guides is important to correctly position the object when added to a deformed structure. This step will allow the slab object, when added, to follow the deformed shape of the girders. The second stage used the “add structure” operation to add the girders as well as the concrete end diaphragms and the intermediate steel diaphragms, and “load object” operation to load the mentioned added objects with their self-weight. Next, five concrete pours were defined in the slab wet concrete load assignment to model five different parts of the pouring process and obtain a time history of the loads under the concrete pouring process. Wet concrete allows the user to model the concrete before it hardens and reaches its full stiffness. Consequently, this load applies only the weight of the concert onto the girders without applying any of their stiffness, as would be the case when the concrete is poured in situ. During the concrete deck pouring process, the slab should have no composite action until the concrete hardens and cures. The pour concrete and remove operations offer a convenient way to model the concrete deck pouring process before and after the concrete cures and hardens. These operations are used in the subsequent steps. Stages 3 to 7 use the “pour concrete operation” along with the wet concrete load defined to model the continuous on-site pouring of wet concrete in five different stages. The pour concrete operation adds in the weight of the concrete pour using the equivalent point and bracket load based on the tributary width for each girder. Finally, the “remove pour” operation is used for all five wet concrete loads applied. The slab is now treated as a structural object and not just a load, as would be the case when the wet concrete cures and hardens. Therefore, stages 3 to 7 model the data collection during the concrete deck pouring process and are used in the comparisons at the end of the chapter.

CSIBridge Data Processing

At each step in the analysis, the internal forces, including the axial forces and the moments, were exported at different stations of the discretized members of the steel diaphragms. A MATLAB script was written to import the mentioned internal forces and calculate the corresponding axial strain at the location of the instrumented sensors (Figure 86). The variation of the strain as a function of the concrete pour stages is shown in Figure 87 through Figure 90.

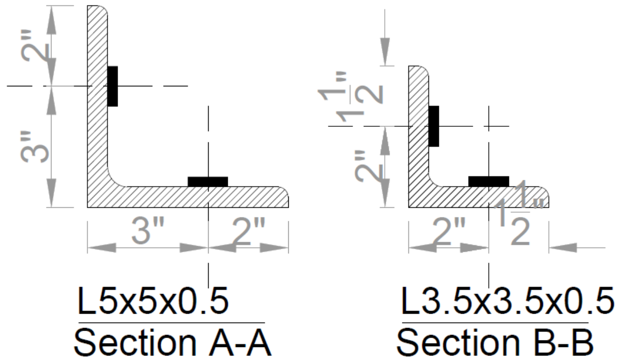


Figure 86. Sketch. Strain gauge location on angle

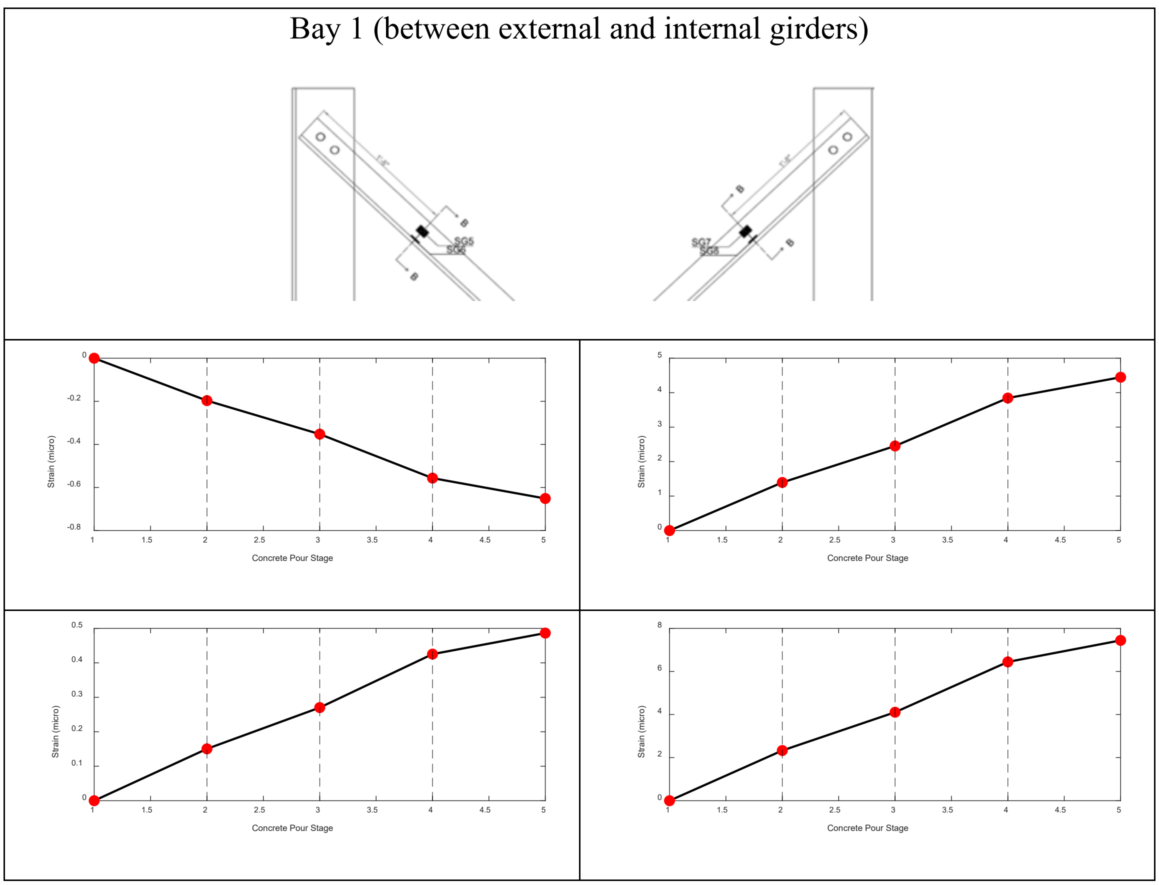


Figure 87. Data. Strain gauge data from top of Bay 1

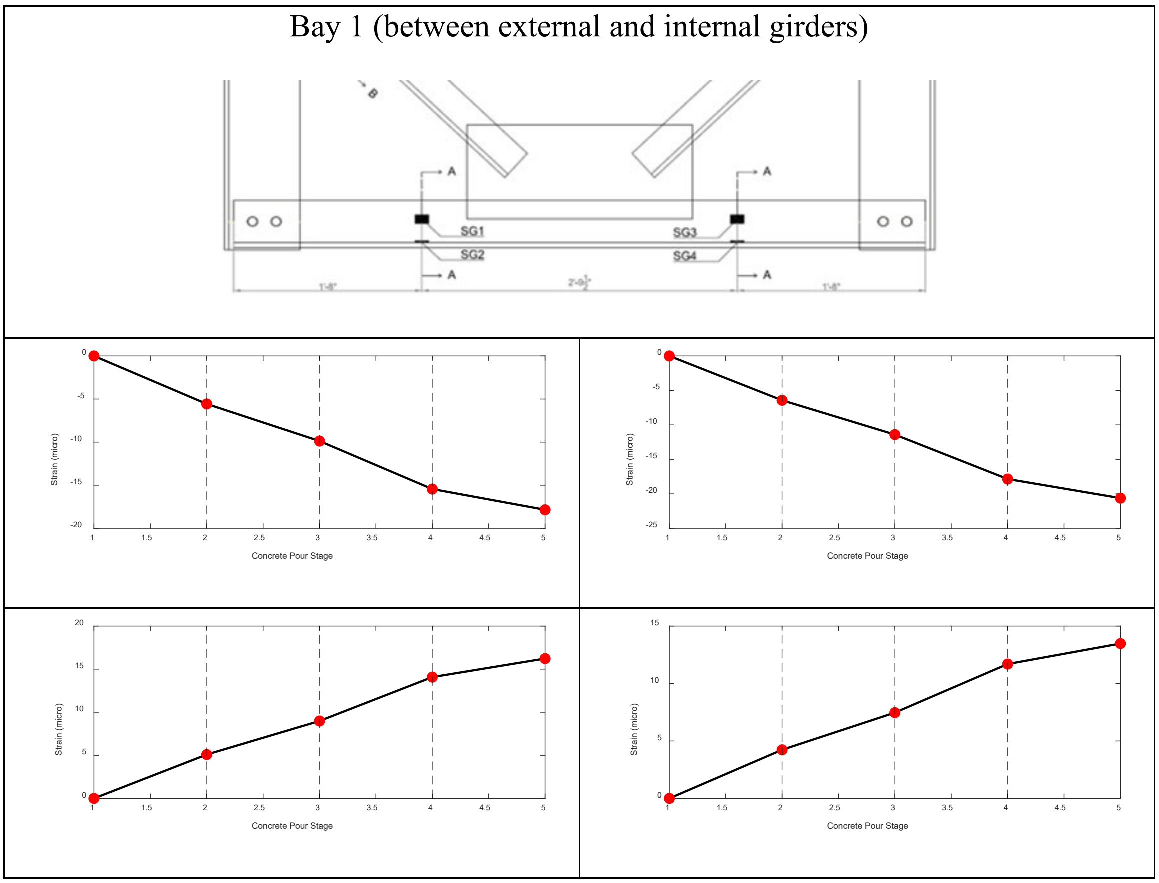


Figure 88. Data. Strain gauge data from bottom of Bay 1

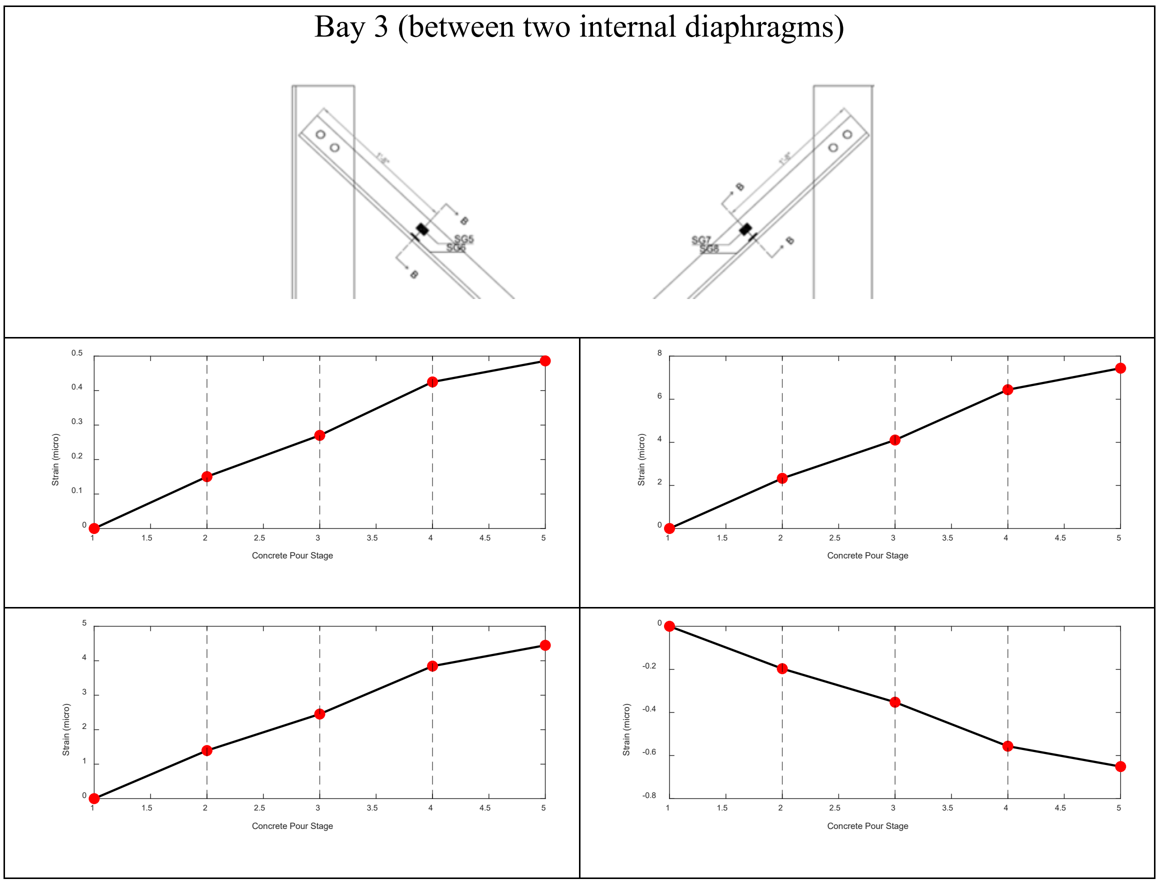


Figure 89. Data. Strain gauge data from top of Bay 3

Bay 3 (between two internal diaphragms)

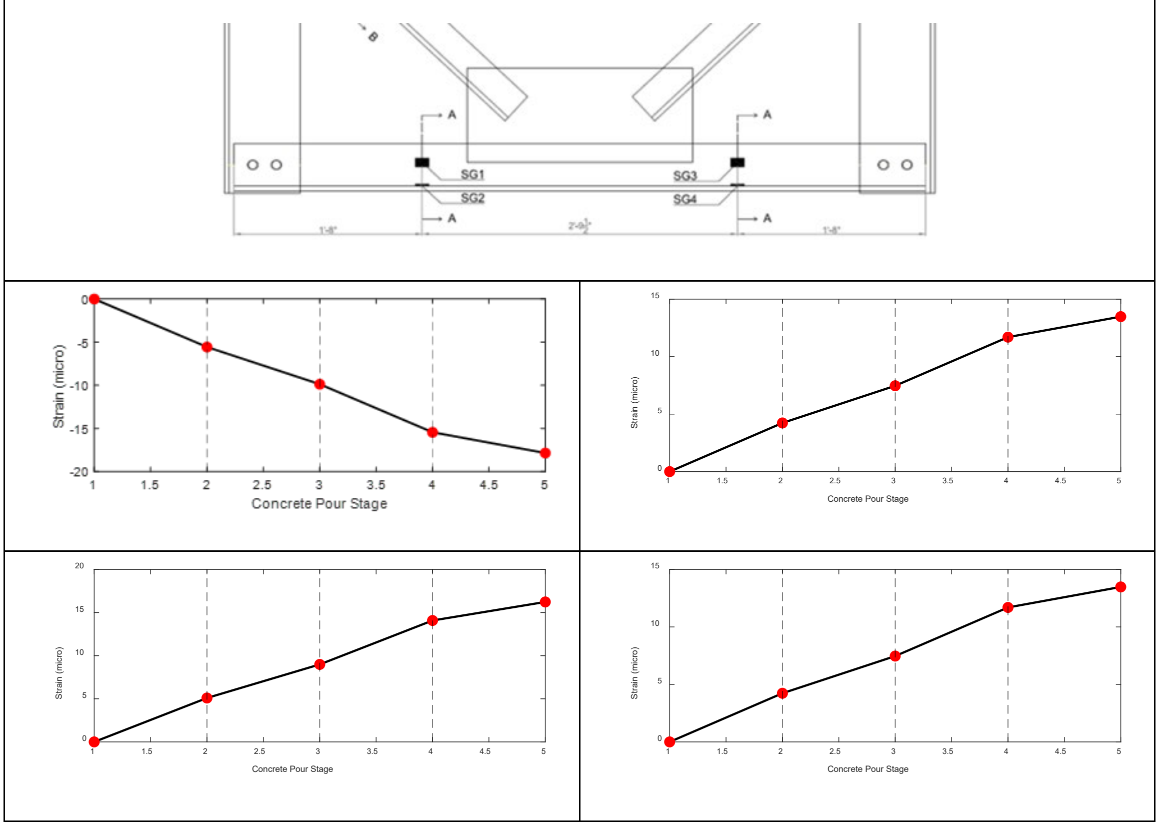


Figure 90. Data. Strain gauge data from bottom of Bay 3

ABAQUS MODEL 1: LABORATORY SIMULATION

To gain a better understanding of the stress distribution in the steel diaphragms, a detailed finite element model of the same scale as the in-situ diaphragm tested was constructed in the commercial finite element software Abaqus.(24) The model consists of 284,000 total nodes and 215,000 linear hexahedral elements, each of type C3D8R. The model is shown in Figure 91 through Figure 93. A fine mesh was chosen such that there are three elements per thickness as shown in Figure 93 to avoid problems with aspect ratio and element bending.

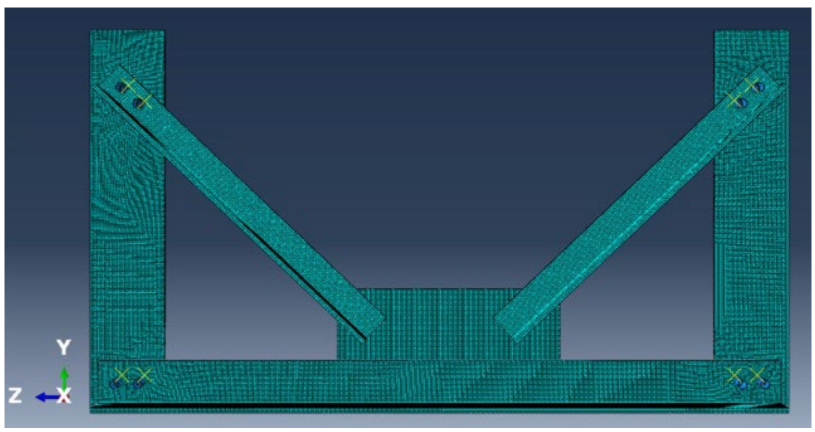


Figure 91. Model. Front view of k-frame diaphragm Abaqus model

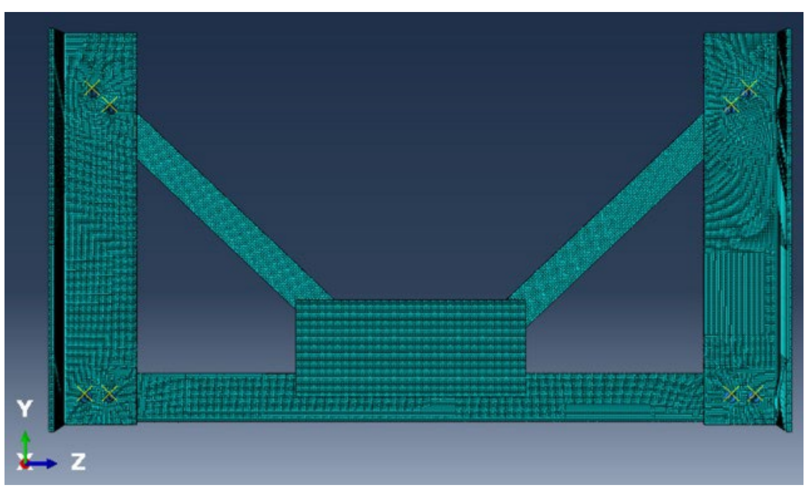


Figure 92. Model. Back view of k-frame diaphragm Abaqus model

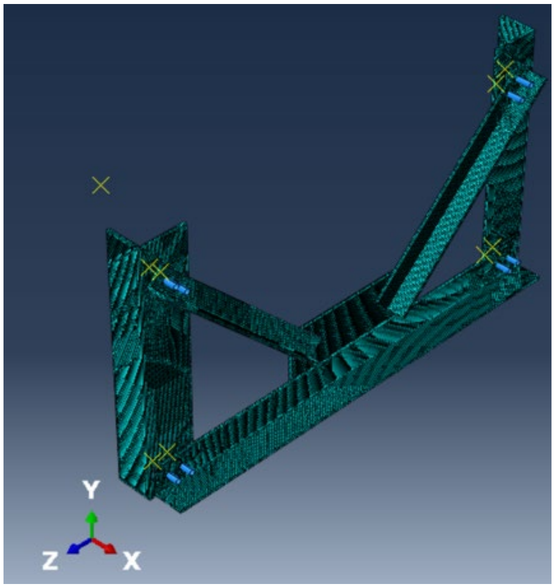


Figure 93. Model. 3D Isometric view of k-frame diaphragm Abaqus model

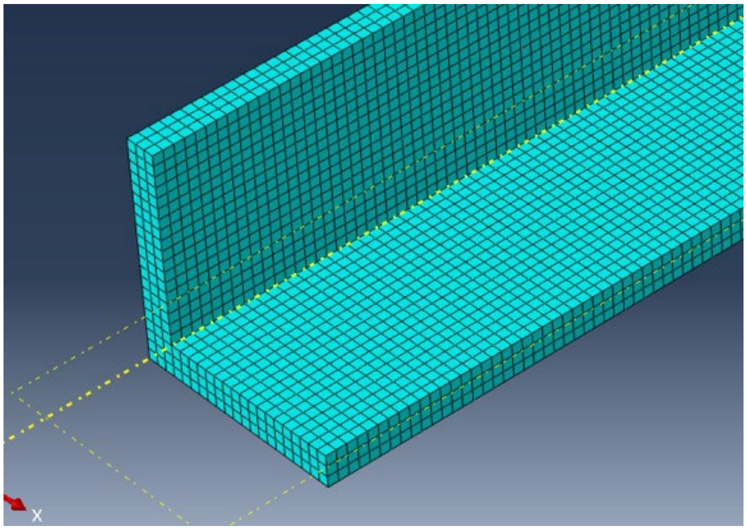


Figure 94. Model. Mesh detail of k-frame diaphragm

To model the interaction between the members of the diaphragm, different constraints were used. Weld constraints were used as interaction between the members and the middle gusset plate for a total of three weld constraints. Additionally, surface-to-surface constraints were used to model the interaction between any two other members in contact. The different interactions are shown in Figure 95.

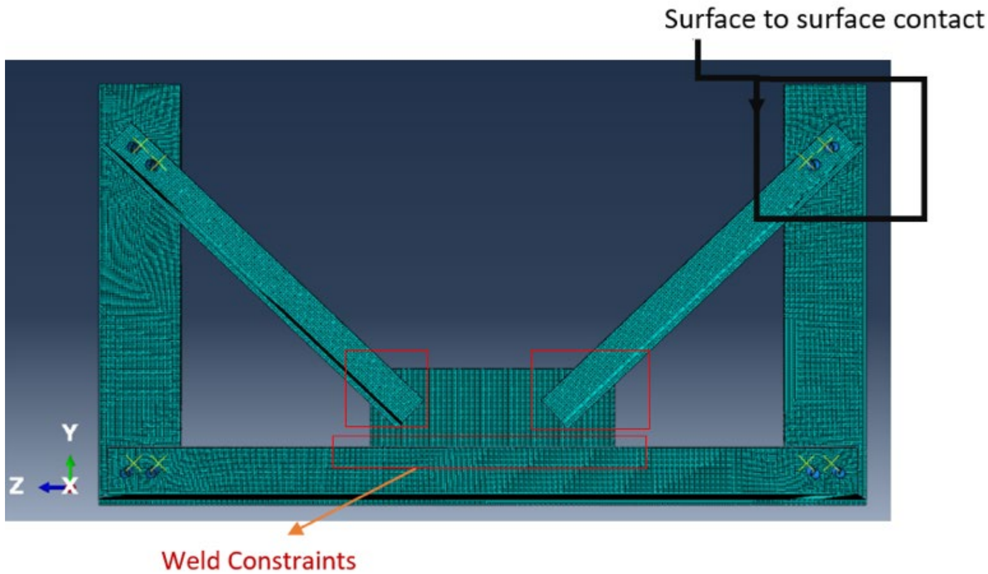


Figure 95. Model. Interactions between members of the k-frame

The bolts connecting the different members were modeled as rigid body cylinders. To better model the bolt behavior, two steps were defined in the job wizard in Abaqus, a contact step followed by a loading step. A reference point was created for each bolt and was linked to the corresponding bolt. Moreover, a no-slip boundary condition was used for the pins, whereby the reference points linked to the bolts were restrained in the contact step (Figure 96). Additionally, a node to surface contact interaction was modeled between the outer surface of the pins and the inner surface of the bolt holes, shown in Figure 97.

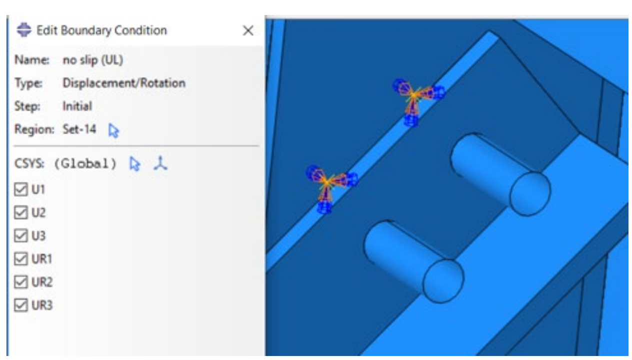


Figure 96. Model. Bolt reference points and no-slip constraints

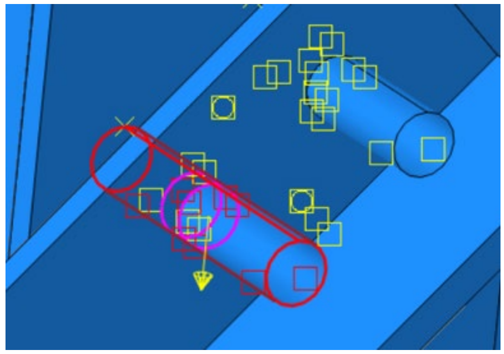


Figure 97. Model. Bolt node to surface contact interaction

The model was used to determine the maximum load to which the diaphragm can be subjected during the same-scale laboratory testing process described earlier. Consequently, the boundary conditions of the diaphragm were modified to match the laboratory test setup. For that purpose, one end of the diaphragm was modeled as fixed, where the rotation and translation were restricted in all directions. The other side of the diaphragm was restrained in the x-direction. A distributed load was applied on the latter end of the diaphragm, and the corresponding strain was examined. It was determined that an appropriate load to use for the test without causing any permanent damage was 10 kips, which was what was executed in the laboratory.

ABAQUS MODEL 2: FIELD SIMULATION

To gain a better understanding into the impact of the construction loads on the k-frame steel diaphragms, additional changes were made to the model described in the previous section to make it more representative of the diaphragm in the field. The concrete girders were modeled in Abaqus to explore the load distribution during the concrete pouring. Since the focus was understanding the strain distribution in the steel k-frame diaphragm, simplified versions of the prestressed reinforced concrete girders were modeled and are shown in Figure 98.

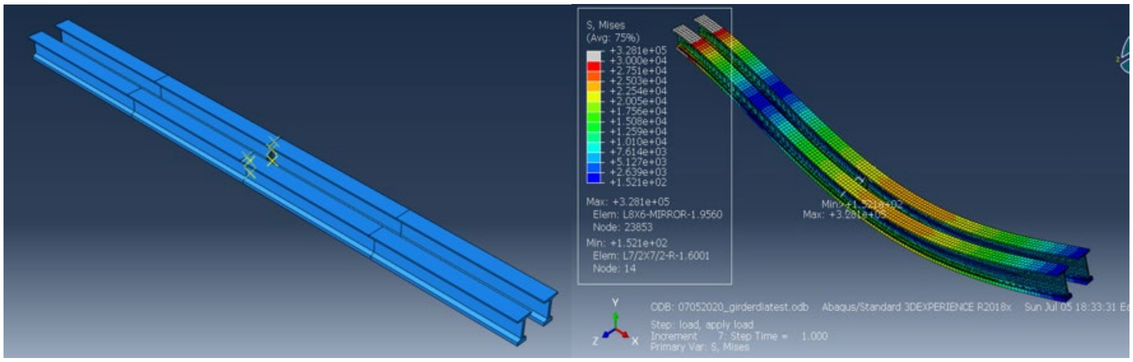


Figure 98. Model. Concrete girders in Abaqus in undeformed (left) and deformed (right) states

The cross section and length of the girders were accurately modeled based on the girder drawings for Span 14 of Bridge 11B. As mentioned, only a simplified version of the girder was modeled, and therefore the prestressing was not taken into consideration. Furthermore, the girder was given an elastic constitutive model with a Young's modulus equal to that of reinforced concrete. To model the boundary conditions, a fixed-expansion model was adopted, whereby one end of the girders had translation constraints in all directions, and the other had translation constraints in the y- and z- directions. The side angles of the diaphragm were connected to the inside of the girders using a tie constraint with the master being the outer side of the angle and the slave being the inner side of the girders, as shown in Figure 99. A tie constraint ties together two separate objects such that there is no relative motion between them and allows two regions with dissimilar meshes to be tied together.

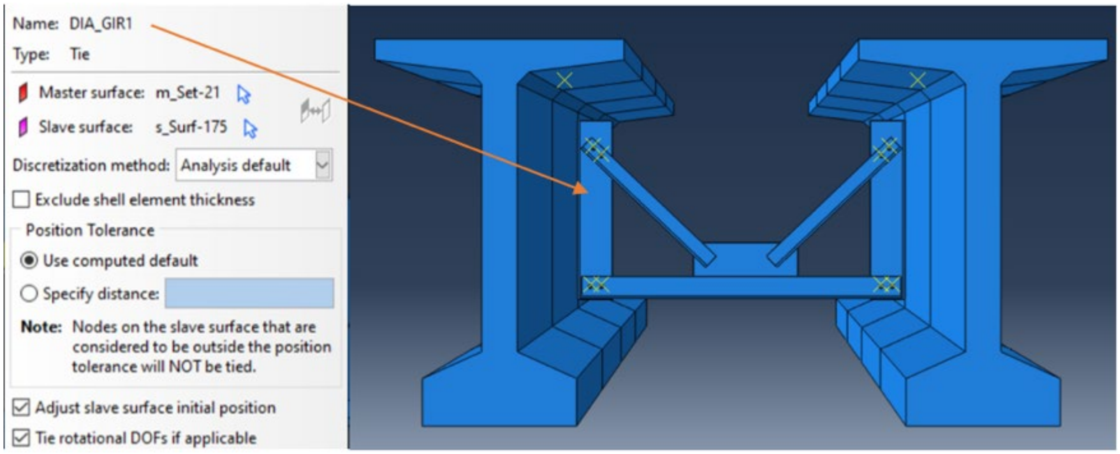


Figure 99. Model. Tie constraint between the steel diaphragm and concrete girders

As mentioned, the model was used to study the strain in the diaphragms caused by the construction loads. This was attained by applying construction loads on the beams to view the resulting effects on the k-frame. For that purpose, the load to be applied was calculated by estimating the weight of concrete needed for the deck pouring.

The deck and beam cross section drawings were used to calculate the weight of the concrete during the concrete deck pouring. Using the dimensions of the deck, the volume of concrete needed was calculated. Moreover, the weight of the concrete was estimated by multiplying the volume with the weight density of concrete. Furthermore, using the tributary width, the loads carried by each girder was then found. Finally, using the surface area of the top of the beams, the distributed load was calculated and used for the simulations. Detailed calculations are given in Appendix E. The pressure caused by the concrete was found to be 1.24 lb/in^2. For that purpose, the beams were partitioned into four parts, with the pressure applied on each quarter representing four stages of concrete deck pour, shown in Figure 100. Strain results of these simulations are calculated and shown in Figure 101 and Figure 102.

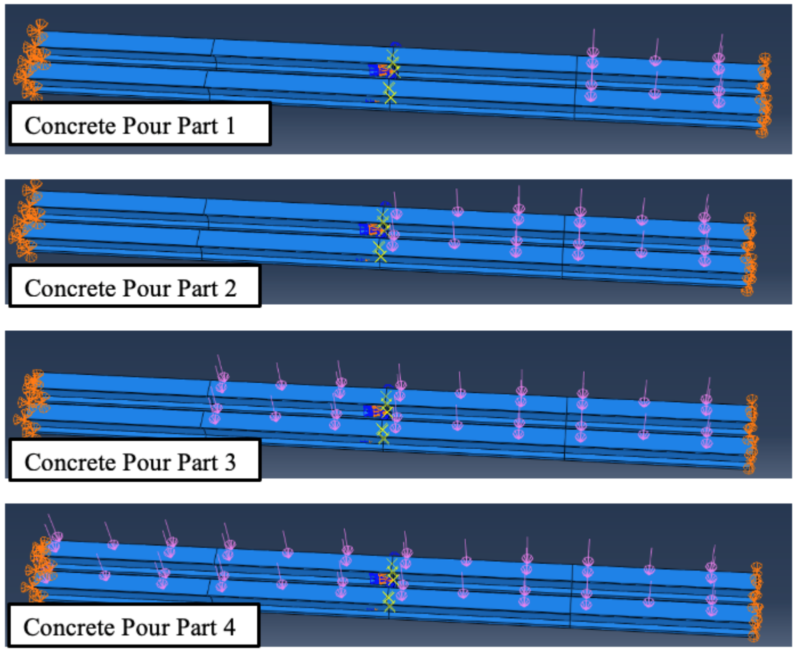


Figure 100. Model. Concrete pour simulation by quarters.

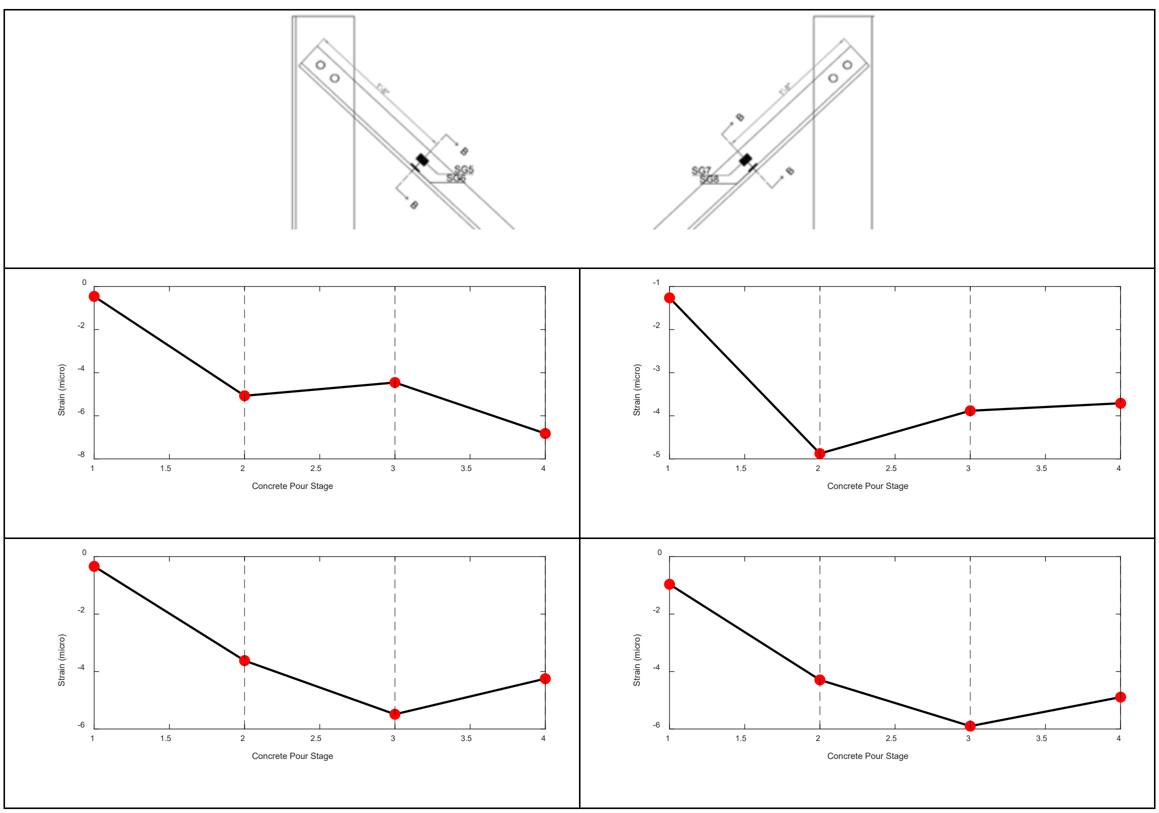


Figure 101. Data. Diagonal member strain results from Abaqus simulation for concrete only

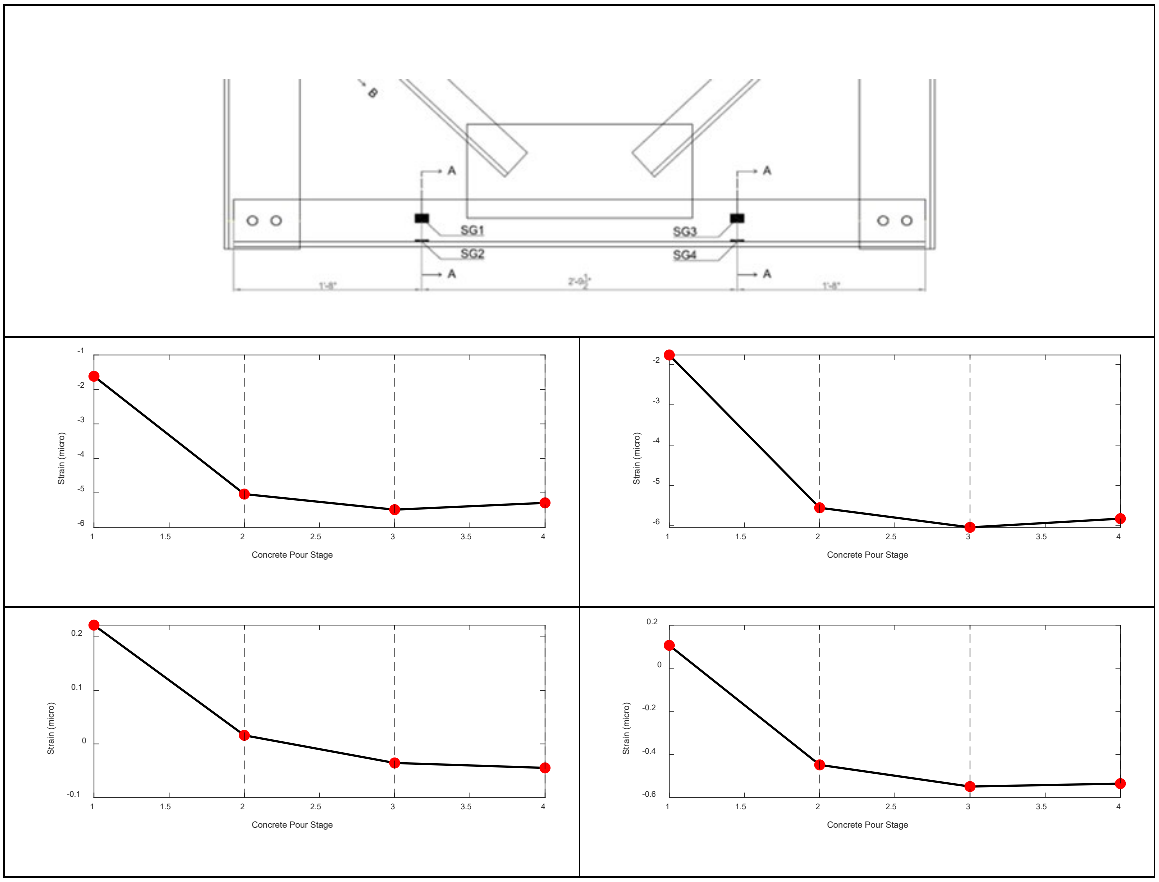


Figure 102. Data. Bottom chord strain results from Abaqus simulation for concrete only

During the examination of the time-lapse footage of the concrete deck pouring, a major construction load identified was the concrete pavement machine, shown in Figure 103. Certain models of these concrete pavement machine weigh up to 20,000 lbs. Consequently, to account for this significant weight, a concentrated force of varying magnitude was added to the mid span of the beams in the Abaqus model, in addition to the distributed load explained previously, as shown in Figure 104.

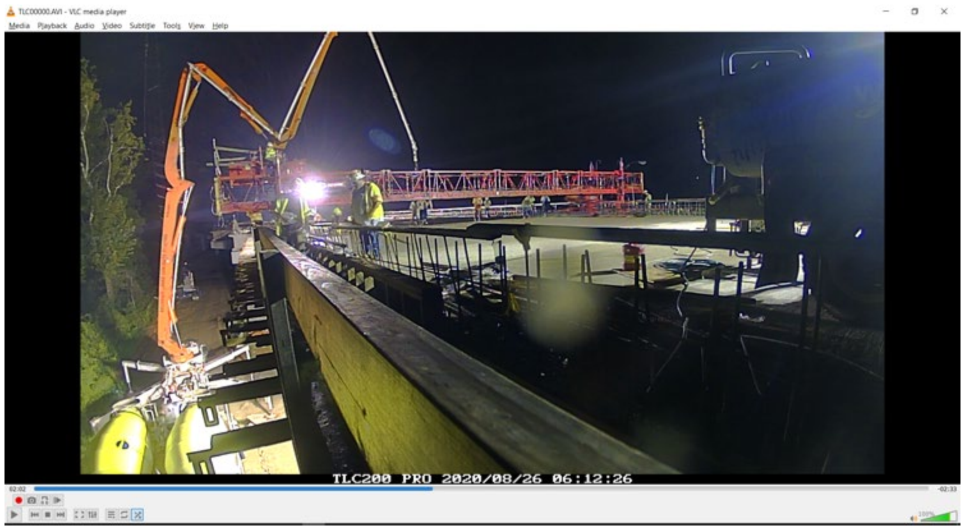


Figure 103. Photo. Identification of the concrete pavement machine as a major construction load from time-lapse camera

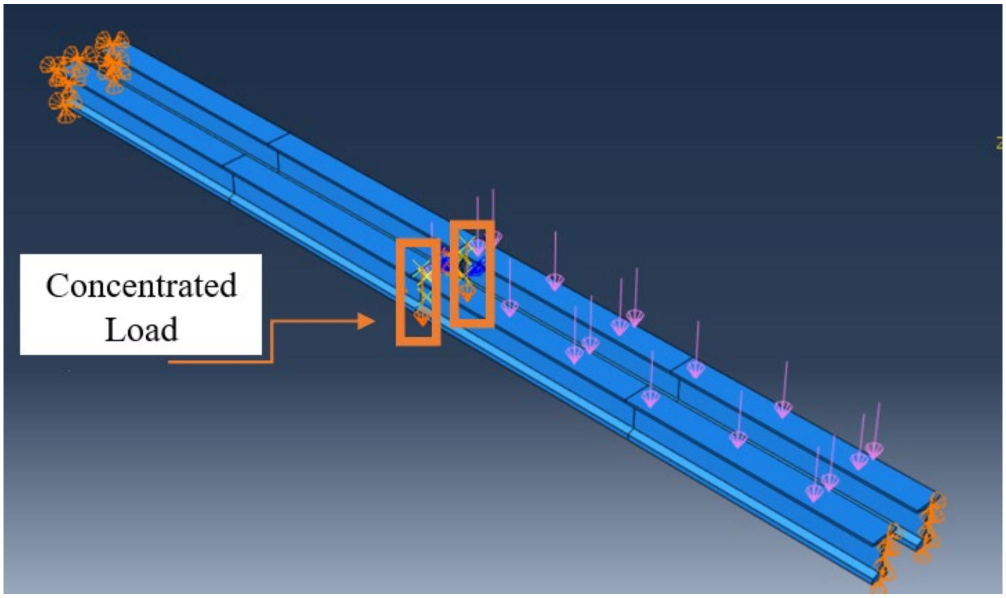


Figure 104. Model. Simulation of halfway point of concrete pouring process: concentrated load at midspan and distributed load

The distributed load was placed onto half of the beam length to simulate half of the concrete pour. The aim was to aim to simulate the steel k-frame diaphragm strain during the halfway point of the concrete deck pouring process. This would consequently mean that half of the concrete deck had been poured and that the concrete paving machine is at the midspan, or directly on top of the diaphragms. Results for this simulation are detailed in the next section. The analysis is run for different magnitude values of the concentrated load modeling the weight of the concrete pavement machine. For all the different load cases, the nodal displacement outputs were exported at two adjacent nodes close to the location of the instrumented strain gauges. Coordinates at the location of the instrumented strain gauge were also exported and used for the calculations. These values were then imported into MATLAB. A MATLAB script was written to read the initial and final nodal displacement values at certain locations and calculated the change in displacement after loading and consequently the induced strain. The strain (in $\mu\epsilon$) obtained at different locations for all members for different values of the concentrated force applied are summarized in Table 6.

Table 6. Summary of micro-strain values for varying load cases in Abaqus

Load Case:	Distributed	Distributed + 5,000lb Force (on each side)	Distributed + 7,000lb Force (on each side)	Distributed + 10,000lb Force (on each side)	Distributed + 7,000lb Force + 8,000lb Force (one on each side)
Strain Gauge 1	-5.034943936	-5.602265686	-5.830869055	-6.179215768	-6.408809117
Strain Gauge 2	0.016107379	-0.020134246	-0.015995304	-0.006298190	-0.000849146
Strain Gauge 3	-5.554543038	-6.165171939	-6.406660206	-6.777852824	-7.022282063
Strain Gauge 4	-0.448738082	-0.547207164	-0.580249465	-0.619059108	-0.647317706
Strain Gauge 5	-5.072218373	-6.208841369	-4.309247012	4.3071912585	-5.211049619
Strain Gauge 6	-3.619596354	-4.732260319	-6.724004692	-5.612233975	-7.632418176
Strain Gauge 7	-4.876654816	-5.339982398	-3.182135119	-5.540292969	-6.208876527
Strain Gauge 8	-4.291231245	-7.606567976	-6.615146514	-5.185465123	-6.974399311

COMPARISONS

Table 7 provides a comparison of the strain values at each of the strain gauge locations. The comparisons include values for both construction loads and wind loads with all the methods developed. The maximum value of strain for each element type (e.g., diagonal) is in bold. From the table, it is evident that there is a wide variation in the strains between the analysis methods. It is important to note that while the field data was recorded during the concrete deck pouring process specifically, the strains obtained could encompass wind loads in addition to the concrete deck pouring and equipment. Generally, the magnitudes of strains recorded during field monitoring are between those provided from the CSIBridge staged construction analysis and CSIBridge wind load analysis.

Additionally, it is also evident that the maximum strains are all caused by the wind condition as opposed to the construction loading, in terms of the locations monitored.

Table 7. Comparison of maximum (absolute value) micro-strain

	Field Monitoring	Construction Loads		Wind Loads	
		CSIBridge	Abaqus	CSIBridge	SAP2000
Strain Gauge 1	76.003	36.083	6.179	83.763	107.008
Strain Gauge 2	68.610	16.231	0.020	**144.074**	107.238
Strain Gauge 3	34.264	20.624	7.022	63.625	68.058
Strain Gauge 4	26.720	25.763	0.647	64.454	68.058
Strain Gauge 5	49.879	37.399	6.209	93.887	58.112
Strain Gauge 6	102.367	39.410	7.632	96.809	56.723
Strain Gauge 7	22.8455	33.083	6.209	94.745	**136.764**
Strain Gauge 8	51.884	31.946	7.607	94.840	134.430

CHAPTER 7. CONCLUSIONS

This research project quantified the effects of construction loads on steel k-frame diaphragms using a combined field monitoring and modeling effort. The main conclusions and recommendations from the research project are as follows:

1. The use of commercial software to model construction loads produced widely-varying strain values for the locations documented in this research effort. It is recommended that engineers use this software with care when specifying boundary and loading conditions, in particular.
2. By comparing the strain values from construction loads determined from various methods with those caused by wind load, it was determined that the wind load is the governing load case. Current AASHTO guidance to design diaphragms using the wind loading condition was verified by this research, at least in terms of the diagonals and chords considered. Therefore, the wind loading case is sufficient to design these elements.
3. Because the bridge was not monitored during the wind load condition, no data is available for some of the diaphragm components. Additional test(s) should be conducted to verify the behavior of the gusset plate, in particular, when subjected to the wind load condition.

APPENDICES

APPENDIX A: DIAPHRAGM CALCULATIONS

STEEL DIAPHRAGM DESIGN CALCULATIONS FOR

AASHTO TYPE II GIRDERS

SPAN 1 & 2 UTILITY BAYS

BRIDGE NO. 29

I-16/I-75 INTERCHANGE

BIBB COUNTY
GEORGIA

NOVEMBER 22, 2017

SHOP DRAWING REVIEW
ENGINEER'S REVIEW
Approved
Approved as Noted
Rejected
Comments Attached

FOR:
HIGHWAY MATERIALS, INC.
5120 OLD DIXIE HIGHWAY
FOREST PARK, GA 30297

GEORGIA REGISTERED
PROFESSIONAL ENGINEER
TIMOTHY L. SCHMITZ

BY:
STRUCTURAL ENGINEERING SOLUTIONS, LLC
3260 ISOLINE WAY
SMYRNA, GA 30080

i

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INTRODUCTION

The attached drawings and calculations are provided for the design analysis of steel diaphragms for AASHTO Type I I girders for beam spacing up to 6'-0" spacing and 64'-0" spans.

Project: Bridge 29, I-16/75 Interchange Bibb County, GA – Utility Bay

Load: 300 plf for 50% of the span length and split between the top and bottom MC8.

Structural Engineering Solutions, LLC
Project: Type I I Girder at 6' spacing and 64 ft long

Eng: tls
Date: 11/22/2017

Steel Diaphragm Load Calculator - Type I I @ 64 ft span

Span Length =	64	ft
Longest Girder Length =	63	ft
Girder Material =	conc	
Girder Type =	Type II	
Girder X-Sect Area =	2.56	ft^2
Unit Weight =	384	plf
Girder Weight =	24192	lbs
Girder Height =	3.00	ft

Concrete	150	pcf		
Steel	490	pcf		
BT-74	819	in^2	5.69	ft^2
BT-72	767	in^2	5.33	ft^2
BT-63	713	in^2	4.95	ft^2
BT-54	659	in^2	4.58	ft^2
Type III	560	in^2	3.89	ft^2
Type II	369	in^2	2.56	ft^2
Type I Mod	332	in^2	2.31	ft^2

Wind: Greater of 50 psf and 300 plf minimum.

50 psf =	150	plf
Minimum Load =	300	plf
USE =	**300**	**plf**
Total Wind Load =	18.9	k
Half Wind to Diaphragm =	9.45	k

Provide tie downs at ends of girders

Diaphragm Load =	**9.45**	**k**

Check KL/r:

MC12 x 31

ry =	1.12	in
k =	1.0	pin - pin
L =	94.5	in = 7'-10 1/2" max
kL/r =	84.375	**kL/r** < 140

OK

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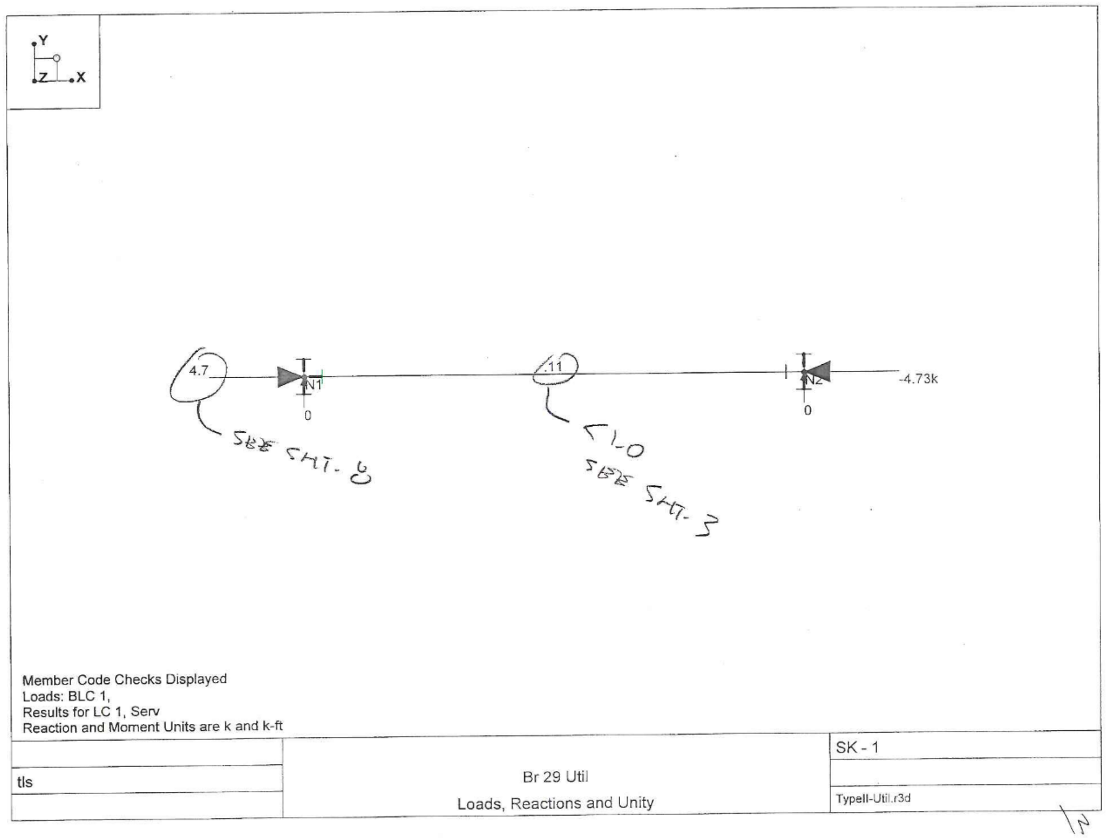
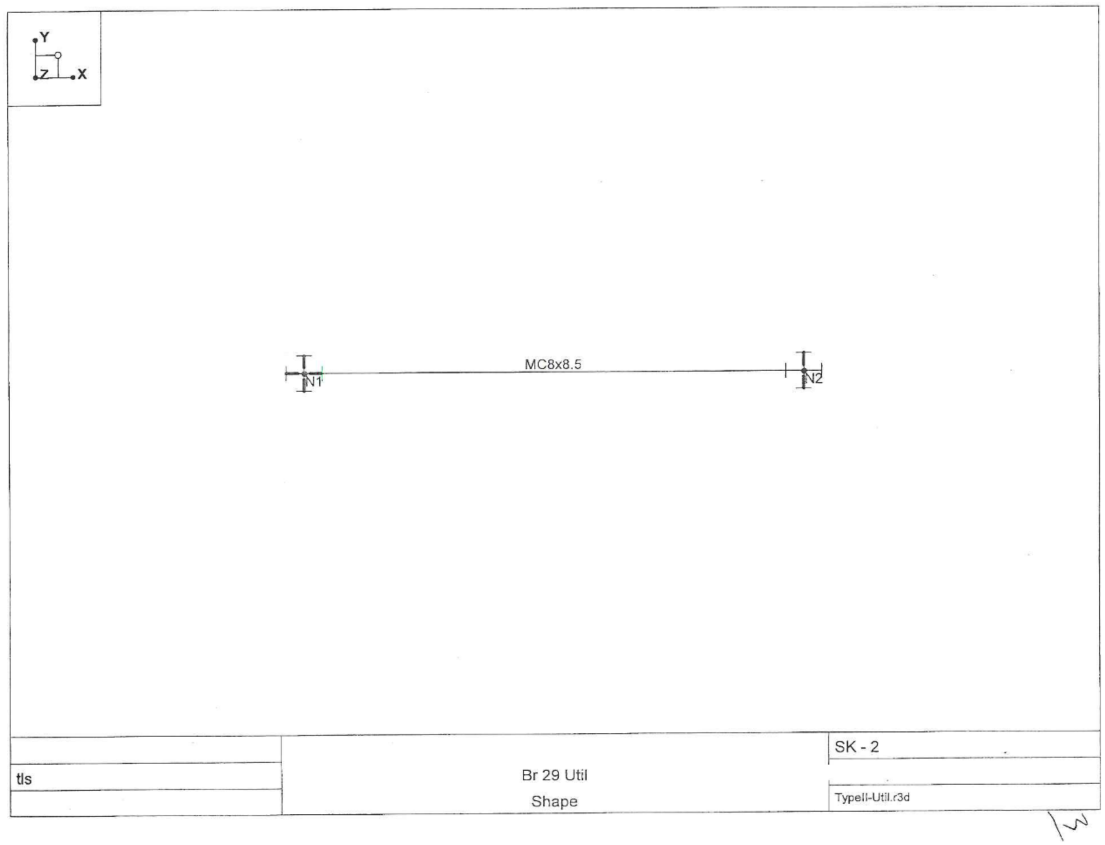
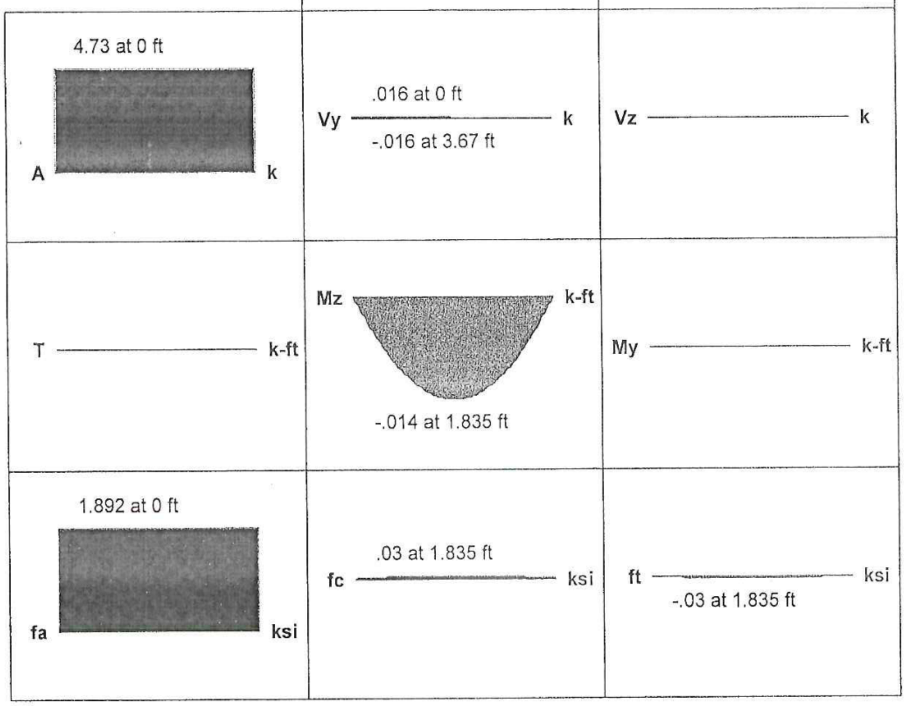

Y
Z
X
4.7
N1
0
.11
N2
0
-4.73k
SEE SHT. 6
< 1.0
SEE SHT. 3
Member Code Checks Displayed
Loads: BLC 1,
Results for LC 1, Serv
Reaction and Moment Units are k and k-ft
tls
Br 29 Util
Loads, Reactions and Unity
SK - 1
TypeII-Util.r3d


Y
Z
X
MC8x8.5
N1
N2
SK - 2
tls
Br 29 Util
Shape
TypeII-Util.r3d

Beam: *M1*

Shape: **MC8x8.5**
Material: **A572 Gr.50**
Length: **3.67 ft**
I Joint: N1
J Joint: N2
LC 1: Serv
Code Check: **0.112 (bending)**
Report Based On 97 Sections



AISC 14th(360-10): ASD Code Check

Direct Analysis Method

Max Bending Check	**0.112**	Max Shear Check	**0.001 (y)**	Max Defl Ratio	**L/10000**
Location	**0 ft**	Location	**3.67 ft**	Location	**0 ft**
Equation	**H1-1b***			Span	**0**

Bending Flange	**Compact**	Compression Flange	**Non-Slender**	**Qs=1**
Bending Web	**Compact**	Compression Web	**Slender**	**Qa=1**

			y-y	z-z
Fy	**50 ksi**	Lb	**3.67 ft**	**3.67 ft**
Pnc/om	**42.408 k**	KL/r	**88.151**	**14.426**
Pnt/om	**74.85 k**			
Mny/om	**1.727 k-ft**	L Comp Flange	**3.67 ft**	
Mnz/om	**15.885 k-ft**	L-torque	**3.67 ft**	
Vny/om	**25.725 k**	Tau_b	**1**	
Vnz/om	**20.895 k**			
Cb	**1.136**			

(Global) Model Settings

Display Sections for Member Calcs	5
Max Internal Sections for Member Calcs	97
Include Shear Deformation?	Yes
Increase Nailing Capacity for Wind?	Yes
Include Warping?	Yes
Trans Load Btwn Intersecting Wood Wall?	Yes
Area Load Mesh (in^2)	144
Merge Tolerance (in)	.12
P-Delta Analysis Tolerance	0.50%
Include P-Delta for Walls?	Yes
Automatically Iterate Stiffness for Walls?	Yes
Max Iterations for Wall Stiffness	3
Gravity Acceleration (ft/sec^2)	32.2
Wall Mesh Size (in)	24
Eigensolution Convergence Tol. (1.E-)	4
Vertical Axis	Y
Global Member Orientation Plane	XZ
Static Solver	Sparse Accelerated
Dynamic Solver	Accelerated Solver

Hot Rolled Steel Code	AISC 14th(360-10): ASD
Adjust Stiffness?	Yes(Iterative)
RISAConnection Code	AISC 14th(360-10): ASD
Cold Formed Steel Code	AISI S100-12: ASD
Wood Code	AWC NDS-12: ASD
Wood Temperature	< 100F
Concrete Code	ACI 318-11
Masonry Code	ACI 530-13: ASD
Aluminum Code	AA ADM1-10: ASD - Building
	AISC 14th(360-10): ASD

Number of Shear Regions	4
Region Spacing Increment (in)	4
Biaxial Column Method	Exact Integration
Parme Beta Factor (PCA)	.65
Concrete Stress Block	Rectangular
Use Cracked Sections?	Yes
Use Cracked Sections Slab?	Yes
Bad Framing Warnings?	No
Unused Force Warnings?	Yes
Min 1 Bar Diam. Spacing?	No
Concrete Rebar Set	REBAR_SET_ASTMA615
Min % Steel for Column	1
Max % Steel for Column	8

(Global) Model Settings, Continued

Seismic Code	ASCE 7-10
Seismic Base Elevation (ft)	Not Entered
Add Base Weight?	Yes
Ct X	.02
Ct Z	.02
T X (sec)	Not Entered
T Z (sec)	Not Entered
R X	3
R Z	3
Ct Exp. X	.75
Ct Exp. Z	.75
SD1	1
SDS	1
S1	1
TL (sec)	5
Risk Cat	I or II
Drift Cat	Other
Om Z	1
Om X	1
Cd Z	1
Cd X	1
Rho Z	1
Rho X	1

Hot Rolled Steel Properties

	Label	E [ksi]	G [ksi]	Nu	Therm (\1E...	Density[k/ft...	Yield[ksi]	Ry	Fu[ksi]	Rt
1	A992	29000	11154	.3	.65	.49	50	1.1	65	1.1
2	A36 Gr.36	29000	11154	.3	.65	.49	36	1.5	58	1.2
3	A572 Gr.50	29000	11154	.3	.65	.49	50	1.1	65	1.1
4	A500 Gr.B RND	29000	11154	.3	.65	.527	42	1.4	58	1.3
5	A500 Gr.B Rect	29000	11154	.3	.65	.527	46	1.4	58	1.3
6	A53 Gr.B	29000	11154	.3	.65	.49	35	1.6	60	1.2
7	A1085	29000	11154	.3	.65	.49	50	1.4	65	1.3

Hot Rolled Steel Section Sets

	Label	Shape	Type	Design List	Material	Design Rules	A [in2]	Iyy [in4]	Izz [in4]	J [in4]
1	MC8	MC8x8.5	Beam	None	A572 Gr.50	Typical	2.5	.624	23.3	.059

Joint Coordinates and Temperatures

	Label	X [ft]	Y [ft]	Z [ft]	Temp [F]	Detach From Diap...
1	N1	0	0	0	0	
2	N2	3.67	0	0	0	

Joint Boundary Conditions

	Joint Label	X [k/in]	Y [k/in]	Z [k/in]	X Rot.[k-ft/rad]	Y Rot.[k-ft/rad]	Z Rot.[k-ft/rad]
1	N1	Reaction	Reaction	Reaction	Reaction	Reaction	
2	N2		Reaction	Reaction	Reaction	Reaction	

7

Member Primary Data

	Label	I Joint	J Joint	K Joint	Rotate(deg)	Section/Shape	Type	Design List	Material	Design Rules
1	M1	N1	N2			MC8	Beam	None	A572 Gr.50	Typical

Member Advanced Data

	Label	I Release	J Release	I Offset[in]	J Offset[in]	T/C Only	Physical	Analysis ...	Inactive	Seismic Design ...
1	M1						Yes			None

Hot Rolled Steel Design Parameters

	Label	Shape	Length[ft]	Lbyy[ft]	Lbzz[ft]	Lcomp top[ft]	Lcomp bot[ft]	L-torqu...	Kyy	Kzz	Cb	Function
1	M1	MC8	3.67			Lbyy						Lateral

Joint Loads and Enforced Displacements (BLC 1 :)

	Joint Label	L,D,M	Direction	Magnitude[(k,k-ft), (in,rad), (k*s^2/ft...
1	N2	L	X	-4.73

Member Distributed Loads

Member Label	Direction	Start Magnitude[k/ft,...	End Magnitude[k/ft,F....	Start Location[ft,%]	End Location[ft,%]
No Data to Print ...					

Basic Load Cases

	BLC Description	Category	X Gravity	Y Gravity	Z Gravity	Joint	Point	Distributed	Area(Me...	Surface(P...
1		None				1				

Moving Loads

Tag	Pattern	Increme...	Both ...	1st Joint	2nd Joint	3rd Joint	4th Joint	5th Joint	6th Joint	7th Joint	8th Joint	9th Joint	10th Joint
No Data to Print ...													

Load Combinations

	Description	Sol...	PD...	SR...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...
1	Serv	Yes	Y		Y	-1	1	1																

STRUCTURAL ENGINEERING SOLUTIONS, LLC
A TRANSPORTATION AND CONSTRUCTION STRUCTURAL ENGINEER

SHEET ______ OF ____
PROJECT NO. ______ DATE ____
PROJECT ____________
SUBJECT:
DES TLS CHK

BOLTS:

2 - 7/8"Ø A325/A449

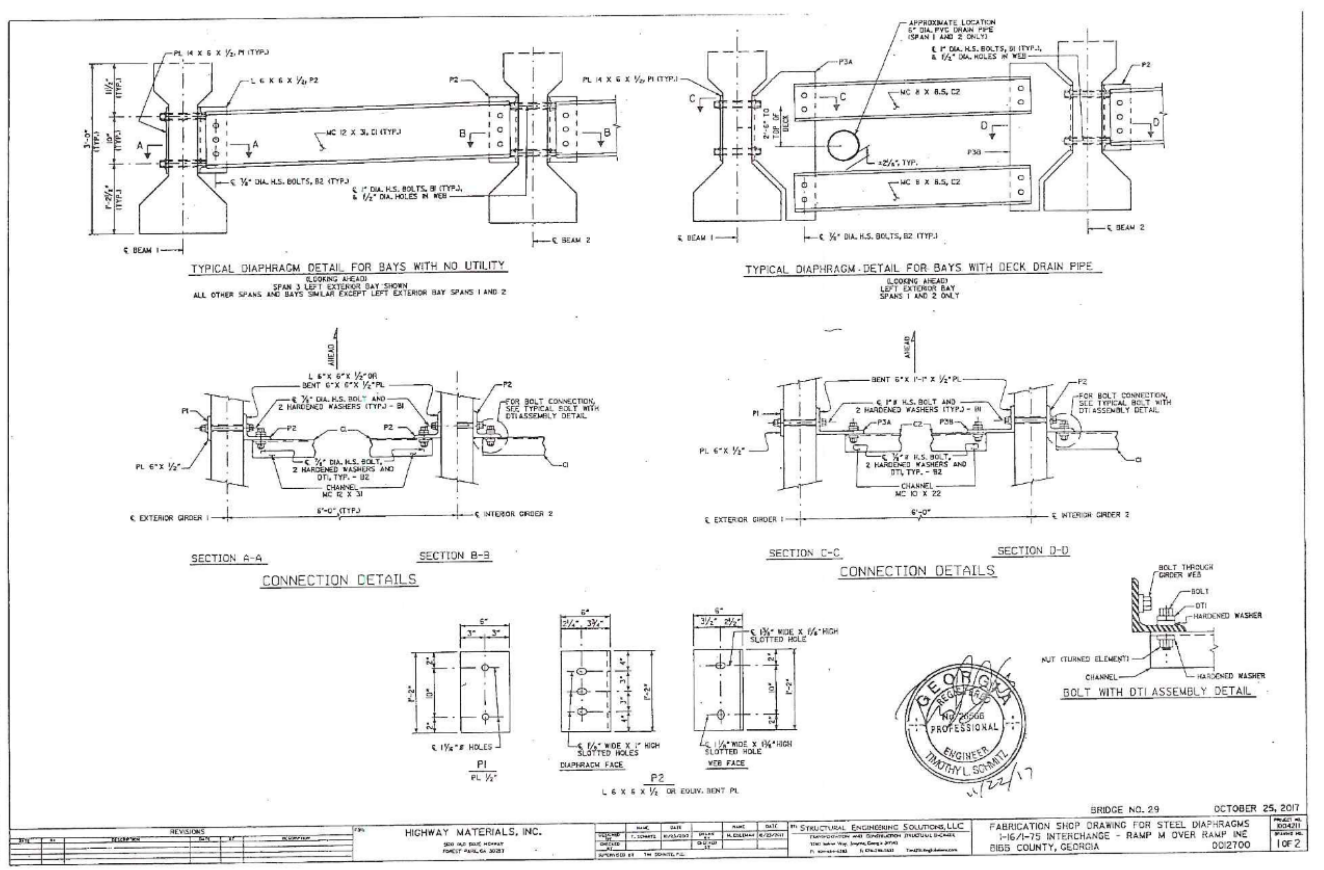
AASHTO 17TH ED., TABLE 10.32.3B

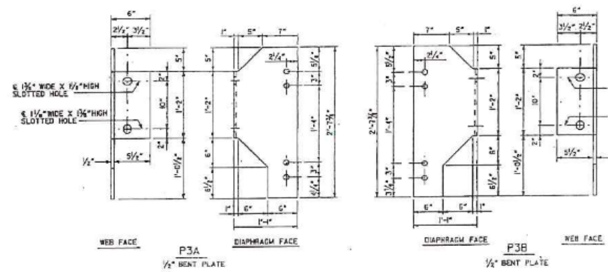
$F_v = 19$ ksi → THR INCL.

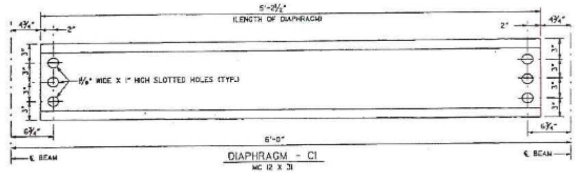
$A_{7/8"Ø} = 0.6013 \text{ in}^2$

$P = 2(0.6013)(19) = 22.8^k >> 4.7^k$

OK

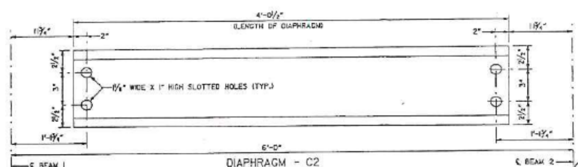

TYPICAL DIAPHRAGM DETAIL FOR BAYS WITH NO UTILITY
TYPICAL DIAPHRAGM-DETAIL FOR BAYS WITH DECK DRAIN PIPE
SECTION A-A
SECTION B-B
CONNECTION DETAILS
SECTION C-C
SECTION D-D
CONNECTION DETAILS
BOLT WITH DTI ASSEMBLY DETAIL
P1
P2
HIGHWAY MATERIALS, INC.
STRUCTURAL ENGINEERING SOLUTIONS, LLC
BRIDGE NO. 29
OCTOBER 25, 2017
FABRICATION SHOP DRAWING FOR STEEL DIAPHRAGMS
I-16/I-75 INTERCHANGE - RAMP M OVER RAMP INE
BIBB COUNTY, GEORGIA
0012700
1 OF 2





DIAPHRAGM - C1

MC 12 X 31



DIAPHRAGM - C2

MC 8 X 8.5

BILL OF MATERIALS FOR ONE SPAN, PROVIDE SPAN QUANTITIES X 2 FOR TOTAL

BILL OF MATERIAL - SPAN 1 TOTAL (SPAN 2 SAME)

	MARK	QTY.	DESCRIPTION	FT	IN	16TH	FAB MARK	MILL MARK	WEIGHT
	TOTAL						TOTAL WT =		844 LBS
		2	PL 6 X 1/2	1	2	0	P1		24
		6	L 6 X 6 X 1/2 OR EQUIV. BENT PL	1	2	0	P2		137
		1	6" X 1'-1" X 1/2" BENT PL	2	7	6	P3A		85
		1	6" X 1'-1" X 1/2" BENT PL	2	7	6	P3B		85
		3	MC 12 X 31	5	2	8	C1		484
		2	MC 8 X 8.5	4	0	8	C2		65
		10	1" ⌀ A449 BOLT, NUT AND WASHERS	0	10	8	B1		
*		24	7/8" ⌀ A449 BOLT, NUT AND WASHERS	0	3	8	B2		

* - PROVIDE TWO HARDENED WASHERS AND ONE DIRECT TENSION INDICATOR (DTI) WASHER PER BOLT.

BILL OF MATERIALS FOR ONE SPAN, PROVIDE SPAN QUANTITIES X 4 FOR TOTAL

BILL OF MATERIAL - SPAN 3 TOTAL (SPANS 4 THRU 6 SAME)

	MARK	QTY.	DESCRIPTION	FT	IN	16TH	FAB MARK	MILL MARK	WEIGHT
	TOTAL						TOTAL WT =		853 LBS
		2	PL 6 X 1/2	1	2	0	P1		24
		8	L 6 X 6 X 1/2 OR EQUIV. BENT PL	1	2	0	P2		183
		4	MC 12 X 31	5	2	8	C1		646
		10	1" ⌀ A449 BOLT, NUT AND WASHERS	0	10	8	B1		
*		24	7/8" ⌀ A449 BOLT, NUT AND WASHERS	0	3	8	B2		

* - PROVIDE TWO HARDENED WASHERS AND ONE DIRECT TENSION INDICATOR (DTI) WASHER PER BOLT.

BILL OF MATERIAL FOR ENTIRE BRIDGE

	MARK	QTY.	DESCRIPTION	FT	IN	16TH	FAB MARK	MILL MARK	WEIGHT
	TOTAL						TOTAL WT =		5180 LBS
		12	PL 6 X 1/2	1	2	0	P1		144
		44	L 6 X 6 X 1/2 OR EQUIV. BENT PL	1	2	0	P2		1006
		2	6" X 1'-1" X 1/2" BENT PL	2	7	6	P3A		170
		2	6" X 1'-1" X 1/2" BENT PL	2	7	6	P3B		170
		22	MC 12 X 31	5	2	6	C1		3552
		4	MC 8 X 8.5	4	0	8	C2		138
		60	1" ⌀ A449 BOLT, NUT AND WASHERS	0	10	8	B1		
*		144	7/8" ⌀ A449 BOLT, NUT AND WASHERS	0	3	8	B2		

* - PROVIDE TWO HARDENED WASHERS AND ONE DIRECT TENSION INDICATOR (DTI) WASHER PER BOLT.

NOTES:

1. ALL STEEL SHALL BE ASTM A709, GR. 50.
2. ALL BOLTS SHALL BE ASTM A325 OR A449 WITH ASTM A563 HEX NUTS AND ASTM F436 HARDENED WASHER UNDER EACH BOLT HEAD AND NUT.
3. ALL BOLTS SHALL BE TIGHTENED IN ACCORDANCE WITH SECTION 501 OF THE GEORGIA SPECIFICATION. IN ABSENCE OF SPECIFICATIONS FOR DTI WASHERS, CONTRACTOR SHALL VERIFY DTI WITH GDOT SPECIFICATIONS APPROVED BOLT TIGHTENING PROCEDURE.
4. ALL STRUCTURAL STEEL MATERIALS INCLUDING BOLTS, NUTS AND WASHERS SHALL BE HOT DIPPED GALVANIZED IN ACCORDANCE WITH ASTM A-123 OR A-125.
5. INTERMEDIATE DIAPHRAGM ASSEMBLY SHALL COMPLY WITH SECTION 851 OF THE GEORGIA STANDARD SPECIFICATIONS.
6. VERIFY BOLT SPACING IN GIRDERS WITH BEAM SHOP DRAWINGS.
7. PLACE AND FINGER TIGHTEN ALL BOLTS BEFORE FINAL TENSIONING. CONTRACTOR SHALL ANTICIPATE ADJUSTMENT OF BOLTS IN SLOTS TO FIT ALL BOLTS.
8. ALL FABRICATION IS TO BE PERFORMED BY HIGHWAY MATERIALS, INC, QPL NO. 59.
9. 1" ⌀ BOLTS SHALL HAVE 3 1/2" MINIMUM OF THREAD LENGTH.
10. AS A MINIMUM, THE STEEL CROSS-FRAMES ARE DESIGNED FOR THE LONG TERM WIND DESIGN LOADS INDUCED ON THE STRUCTURE. STABILITY OF THE PRESTRESSED BEAMS DURING ALL PHASES OF CONSTRUCTION SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR. THE CONTRACTOR SHALL PROVIDE ANY TEMPORARY BRACING OR SUPPORT NECESSARY TO ENSURE STABILITY OF THE STRUCTURE UNTIL CONSTRUCTION IS COMPLETE.

GEORGIA REGISTERED No. 26566 PROFESSIONAL ENGINEER TIMOTHY L. SCHMITZ

11/22/17

BRIDGE NO. 29 — OCTOBER 25, 2017

REVISIONS

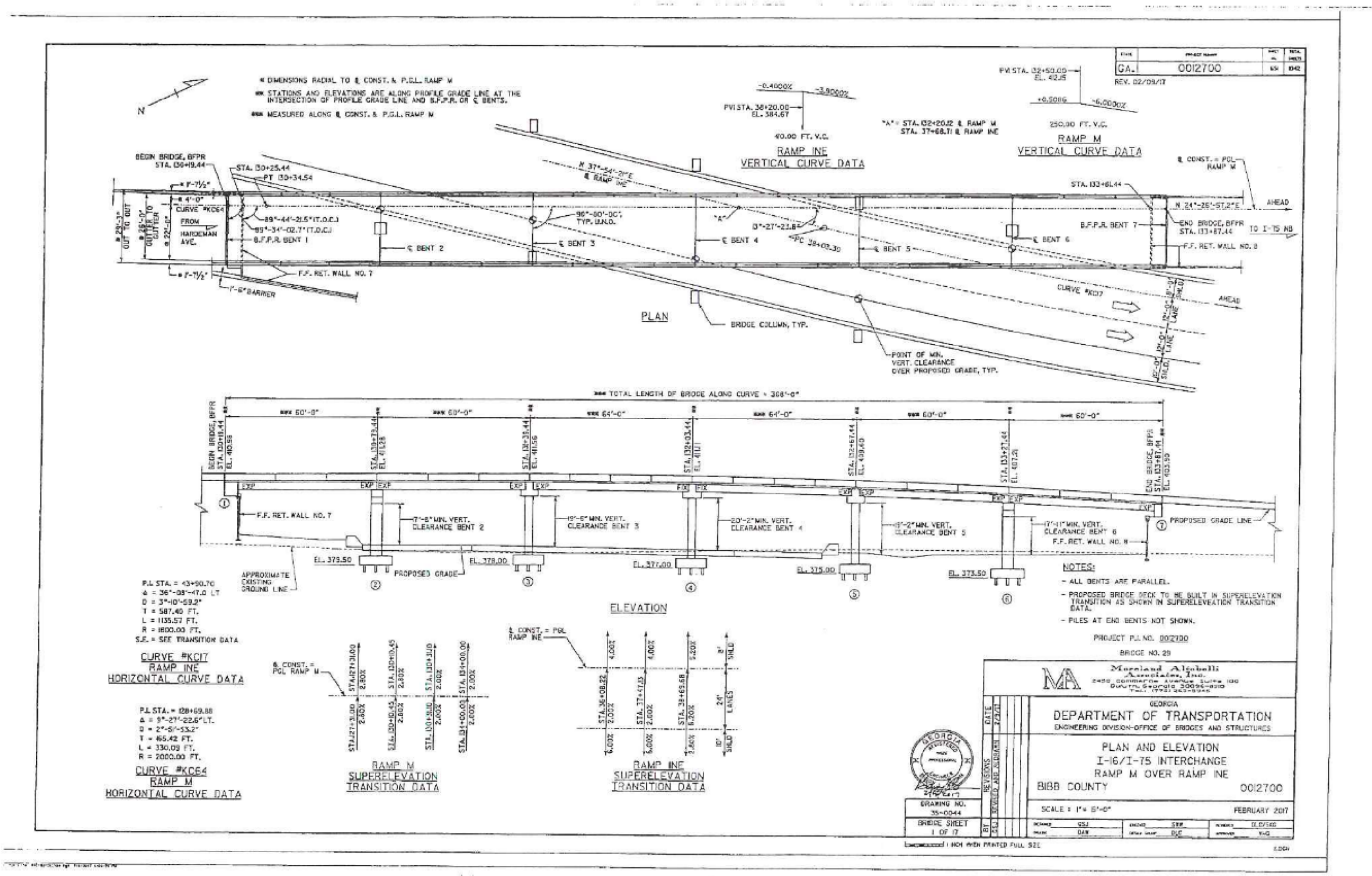
HIGHWAY MATERIALS, INC.

STRUCTURAL ENGINEERING SOLUTIONS, LLC

FABRICATION SHOP DRAWING FOR STEEL DIAPHRAGMS
I-16/I-75 INTERCHANGE - RAMP M OVER RAMP INE
BIBB COUNTY, GEORGIA
0012700

PROJECT NO. 1004211

DRAWING NO. 2 OF 2


PLAN
ELEVATION
RAMP INE
VERTICAL CURVE DATA
RAMP M
VERTICAL CURVE DATA
CURVE #KC17
RAMP INE
HORIZONTAL CURVE DATA
CURVE #KC64
RAMP M
HORIZONTAL CURVE DATA
RAMP M
SUPERELEVATION
TRANSITION DATA
RAMP INE
SUPERELEVATION
TRANSITION DATA
NOTES:
- ALL BENTS ARE PARALLEL.
- PILES AT END BENTS NOT SHOWN.
GEORGIA
DEPARTMENT OF TRANSPORTATION
PLAN AND ELEVATION
I-16/I-75 INTERCHANGE
RAMP M OVER RAMP INE
BIBB COUNTY
0012700
FEBRUARY 2017

B1

STATE	PROJECT NUMBER	SHEET NO.	TOTAL SHEETS
GA.	0012700	652	1042

REV. 02/09/17

BRIDGE CONSISTS OF

4 - 60'-0" TYPE II PSC BEAM SPANS ---------------------------- SPECIAL DESIGN
2 - 64'-0" TYPE II PSC BEAM SPANS ---------------------------- SPECIAL DESIGN
2 - STEEL H PILE END BENTS WITH MSE ABUTMENT WALLS------------ SPECIAL DESIGN
5 - CONCRETE INTERMEDIATE BENTS ------------------------------ SPECIAL DESIGN
BAR BENDING DETAILS ------------------------------ GA. STD. 3901 (6-69)
TYPICAL FILL DETAIL AT END OF BRIDGE -------------- GA. STD. 9037 (9-99)

TRAFFIC DATA

TRAFFIC -- ADT = 3,450 (2016)
ADT = 4,050 (2036)
DESIGN SPEED -- 35 MPH
TRUCKS --- 10 %
24 HR TRUCKS --7 %
DIRECTIONAL ---100 %

UTILITIES

NO UTILITIES ON BRIDGE

GENERAL NOTES

SPECIFICATIONS - GEORGIA STANDARD SPECIFICATIONS, 2013 EDITION, AS MODIFIED BY CONTRACT DOCUMENTS.

REINFORCING STEEL - PLACE AND TIE ALL REINFORCING STEEL IN ACCORDANCE WITH THE GEORGIA DOT SPECIFICATIONS. DO NOT WELD REINFORCING STEEL.

CHAMFER - CHAMFER ALL EXPOSED CONCRETE EDGES 3/4" UNLESS OTHERWISE NOTED.

TRAFFIC CONTROLS - SEE ROADWAY PLANS FOR TRAFFIC CONTROLS AND TRAFFIC CONTROL PAYMENT.

WAITING PERIOD - NONE REQUIRED.

⚠ FOUNDATION BACKFILL MATERIAL - PLACE 1'-0" OF TYPE II FOUNDATION BACKFILL MATERIAL UNDER EACH FOOTING AT BENTS 2 - 6. THE QUANTITY IS BASED ON THE PLAN FOOTING DIMENSIONS PLUS 2'-0".

PLAN DRIVING OBJECTIVE - SEE SUBSTRUCTURE DETAILS.

DRIVING DATA PILES - ONE DRIVING DATA PILE SHALL BE REQUIRED AT EACH OF BENTS 1, 4, AND 7.

SMOOTH DOWEL BARS - PLACE SMOOTH DOWEL BARS IN FORMED 3" DIAMETER X 12" DEEP HOLES AND GROUT IN PLACE SIMILAR TO ANCHOR BOLTS, SEE SUB-SECTION 501.3.05.B.3 OF THE GEORGIA DOT SPECIFICATIONS. STIRRUPS MAY BE SHIFTED SLIGHTLY TO CLEAR FORMED HOLES.

ABUTMENT SOIL REINFORCING DEVICE INSERTS - INCLUDE THE COST OF FURNISHING AND INSTALLING INSERTS FOR SOIL REINFORCING DEVICES AT ABUTMENT IN THE OVERALL BID SUBMITTED.

STANDARD PLAN MODIFICATION - MODIFY THE APPROACH SLAB STANDARDTO INCREASE THE 3/4 " EXPANSION JOINT SHOWN BETWEEN THE APPROACH SLAB AND THE BACK FACE PAVING REST AND END POST TO 1". SEE ROADWAY PLANS FOR APPROACH SLAB PAYMENT.

GROOVED CONCRETE - GROOVE THE ENTIRE LENGTH OF THE BRIDGE TRANSVERSELY AS PER SUB-SECTION 500.3.05.T.9.C OF THE GEORGIA DOT SPECIFICATIONS.

WELDING - ALL WELDING ON GEORGIA DOT PROJECTS SHALL BE PERFORMED BY CERTIFIED WELDERS THAT HAVE IN THEIR POSSESSION A CURRENT WELDING CERTIFICATION CARD ISSUED BY THE OFFICE OF MATERIALS AND TESTING. USE ONLY E70XX (EXCLUDING E7014 AND E7024) LOW HYDROGEN ELECTRODES FOR MANUAL SHIELDED METAL ARC WELDING.

INCIDENTAL ITEMS - INCLUDE THE COST INCIDENTAL TO THE WORK THAT IS NOT SPECIFICALLY COVERED BY THE GEORGIA STANDARD SPECIFICATIONS, SUPPLEMENTAL SPECIFICATIONS AND/OR SPECIAL PROVISIONS IN THE OVERALL BID SUBMITTED. THIS INCLUDES THE COST OF WATERPROOFING, JOINT FILLERS, AND OTHER INCIDENTAL ITEMS NECESSARY TO COMPLETE THE WORK.

DESIGN DATA

SPECIFICATIONS ------------------------------ AASHTO 17TH EDITION, 2002
(DESIGNED FOR SEISMIC PERFORMANCE CATEGORY A)
TYPICAL HS20-44 AND/OR MILITARY LOADING -------------------- IMPACT ALLOWED
FUTURE PAVING ALLOWANCE ------------------------------ 30 LBS PER SQ FT
CONCRETE: SUPERSTRUCTURE ------------------------ CLASS AA, f'_c = 3,500 PSI
BARRIER --------------------------------- CLASS AA, f'_c = 3,500 PSI
PSC BEAMS ------------------------------ CLASS AAA, f'_c = 6,000 PSI
PSC BEAM ALLOWABLE TENSION ------------------------------ 465 PSI
SUBSTRUCTURE -------------------------- CLASS AA, f'_c = 3,500 PSI
REINFORCEMENT STEEL: ---------------------------- GRADE 60, f_y = 60,000 PSI
PRETENSIONING STRANDS: ------------------------------------ f_s = 270,000 PSI
STEEL H-PILES: --------------------------------- GRADE 36, f_y = 36,000 PSI

SUMMARY OF QUANTITIES

	PAY ITEM NUMBER	QUANTITY	UNIT	PAY ITEM
⚠	207-0203	56	CY	FOUND BKFILL MATL, TP II
	211-0200	483	CY	BRIDGE EXCAVATION, GRADE SEPARATION
⚠	449-1350	59	LF	PREFORMED SILICONE JOINT SEAL, BR NO - 29
	500-0100	981	SY	GROOVED CONCRETE
	500-1006	LUMP	LS	SUPERSTR CONCRETE, CL AA, BR NO - 29 (278)
	500-2100	736	LF	CONCRETE BARRIER
⚠	500-3002	517	CY	CLASS AA CONCRETE
	507-9002	1765	LF	PSC BEAMS, AASHTO TYPE II, BR NO - 29
⚠	511-1000	141292	LB	BAR REINF STEEL
	511-3000	LUMP	LS	SUPERSTR REINF STEEL, BR NO - 29 (84622)
	520-1104	800	LF	PILING IN PLACE, STEEL H, HP 10 X 42
	520-1147	1700	LF	PILING IN PLACE, STEEL H, HP 14 X 73
	520-4104	1	EA	LOAD TEST, STEEL H, HP 10 X 42 (IF REQD)
	520-4147	1	EA	LOAD TEST, STEEL H, HP 14 X 73 (IF REQD)
	544-1000	LUMP	LS	DECK DRAIN SYSTEM, BR NO - 29

BRIDGE NO. 29

Moreland Altobelli Associates, Inc.
2450 Commerce Avenue Suite 100
Duluth, Georgia 30096-8910
Tel: (770) 263-5945

GEORGIA
DEPARTMENT OF TRANSPORTATION
ENGINEERING DIVISION-OFFICE OF BRIDGES AND STRUCTURES

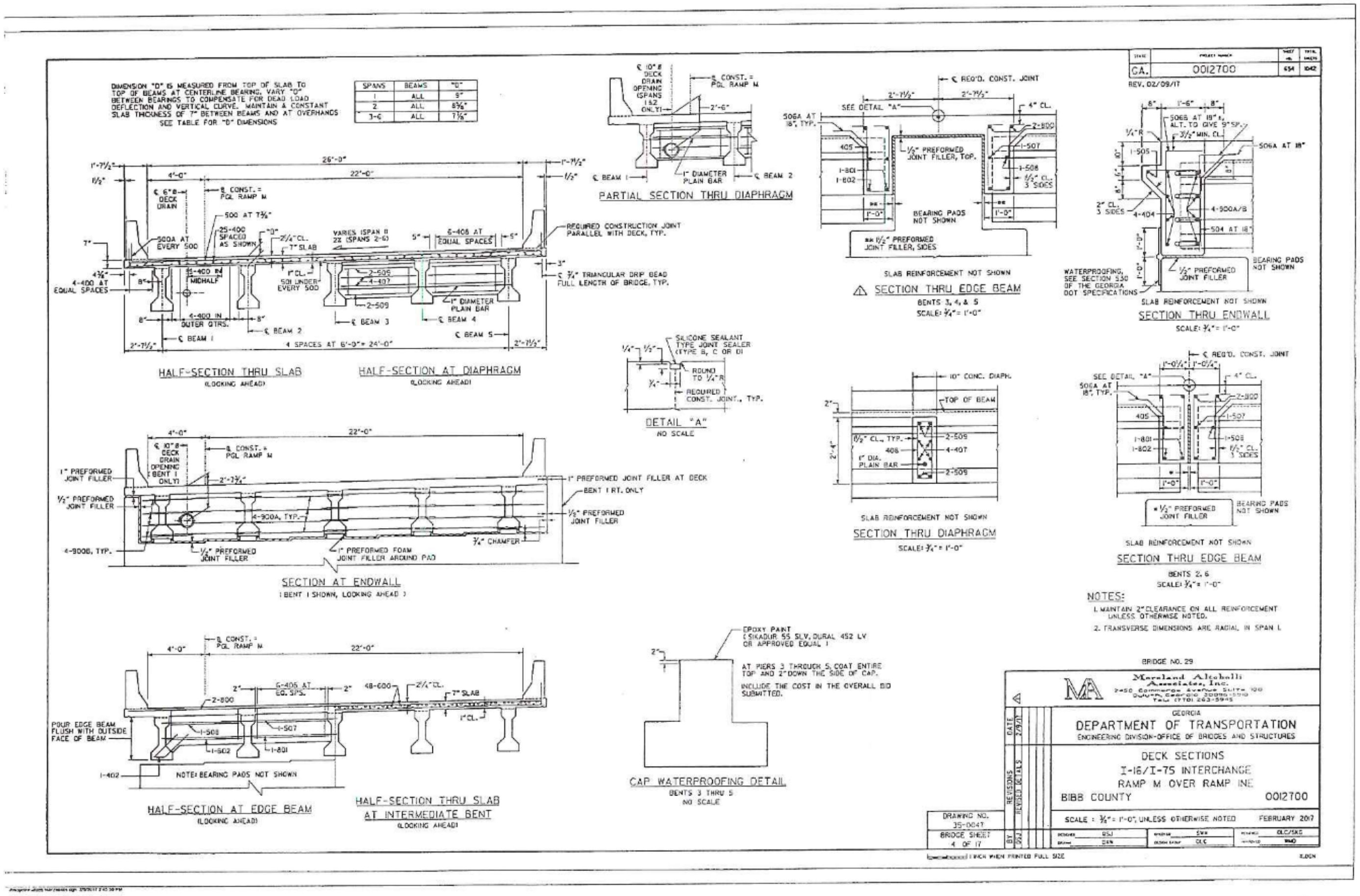
GENERAL NOTES
I-16/I-75 INTERCHANGE
RAMP M OVER RAMP INE
BIBB COUNTY 0012700

REVISIONS: DATE 2/3/17 — REV. NOTES AND QTYS — BY DSJ

DRAWING NO. 35-0045
BRIDGE SHEET 2 OF 17
SCALE : NONE
FEBRUARY 2017
DSJ · SWW · DLC/SEG · DAW · DLC · MWD

1 INCH WHEN PRINTED FULL SIZE

132



HALF-SECTION THRU SLAB
(LOOKING AHEAD)
HALF-SECTION AT DIAPHRAGM
(LOOKING AHEAD)
PARTIAL SECTION THRU DIAPHRAGM
SECTION THRU EDGE BEAM
BENTS 3, 4, & 5
SECTION THRU ENDWALL
DETAIL "A"
NO SCALE
SECTION THRU DIAPHRAGM
SECTION AT ENDWALL
(BENT 1 SHOWN, LOOKING AHEAD)
SECTION THRU EDGE BEAM
BENTS 2, 6
SCALE: ¼" = 1'-0"
NOTES:
1. MAINTAIN 2" CLEARANCE ON ALL REINFORCEMENT UNLESS OTHERWISE NOTED.
2. TRANSVERSE DIMENSIONS ARE RADIAL IN SPAN 1.
HALF-SECTION AT EDGE BEAM
(LOOKING AHEAD)
HALF-SECTION THRU SLAB AT INTERMEDIATE BENT
(LOOKING AHEAD)
CAP WATERPROOFING DETAIL
BENTS 3 THRU 5
NO SCALE
BRIDGE NO. 29
Moreland Altobelli Associates, Inc.
GEORGIA
DEPARTMENT OF TRANSPORTATION
ENGINEERING DIVISION-OFFICE OF BRIDGES AND STRUCTURES
DECK SECTIONS
I-16/I-75 INTERCHANGE
RAMP M OVER RAMP INE
BIBB COUNTY
0012700
SCALE : ⅛" = 1'-0", UNLESS OTHERWISE NOTED
FEBRUARY 2017
DRAWING NO. 35-0047
BRIDGE SHEET 4 OF 17

B3

Calculations for Steel Diaphragms For Wind Loads

BT-63 – Spans 2 – 8

DATE: 07-Mar-2018

Approved in general. Details not checked. This approval shall not relieve the Contractor of any responsibility for conformity with the contract Plans and Specifications.

Bridge 10

I-16/I-75 Interchange

Georgia DOT
Office of Bridge Design
By: EMH

NHIM0-0016-01(092)

Bibb County
Georgia

January 13, 2018

SHOP DRAWING REVIEW

ENGINEER'S REVIEW		RESPONSE REQUIRED OF CONTRACTOR
Approved [x]	Rejected [ ]	Resubmit [ ]
Approved as Noted [ ]	Comments Attached [ ]	Confirm [ ]

Engineer's review for general conformance with the design concept and contracts documents. Markings or comments shall not be construed as relieving the Contractor from compliance with the project plans and specifications, nor departures therefrom. the Contractor remains responsible for details and accuracy, for confirming and correlating all quantities and dimensions, for selecting fabrication process, for techniques of assembly, and for performing his work in a safe manner.

Long Engineering INC.
By: SLP DATE: 03-05-2018

GEORGIA REGISTERED No. 25566 PROFESSIONAL ENGINEER TIMOTHY L. SCHMITZ
1/13/18

Submitted by:

Highway Materials, Inc.
5120 Old Dixie Highway
Forest Park, GA 30297

By:

Structural Engineering Solutions, LLC
3260 Isoline Way
Smyrna, GA 30080

TABLE of CONTENTS

DATE: 07-Mar-2018

Approved in general. Details not checked. This approval shall not relieve the Contractor of any responsibility for conformity with the contract Plans and Specifications.

Georgia DOT
Office of Bridge Design
By: EMH

INTRODUCTION

The following calculations and documentation is provided to support the diaphragm redesign for Span 1 using steel K-frames for I-16/75 Interchange, Bridge 10 – Spans 2 - 8, Bibb County, Georgia.

GDOT Criteria:
Load: Greater of 50 psf and 300 plf.
kL/r < 140 for members.

The diaphragm is loaded with 50% of the girder length for wind load. This load is applied as half to the top diagonal and half to the bottom horizontal leg as a lateral load (global x-axis).

RISA-3D analyzes the single angle consider the weak principal axis (y'-y' in RISA and z-z in AISC). See Appendix C for explanation of the principal axis due to the unsymmetrical single angle.

Structural Engineering Solutions, LLC
Project: I-16/75 Br. 10

Eng: tls
Date: 1/9/2018

Steel Diaphragm Load Calculator - Spans 2-8 - BT 63

Span Length =	130.5	ft
Longest Girder Length =	129.5	ft
Girder Material =	conc	
Girder Type =	BT-63	
Girder X-Sect Area =	4.95	ft^2
Unit Weight =	743	plf
Girder Weight =	96154	lbs
Girder Height =	5.25	ft

Concrete	150 pcf		
Steel	490 pcf		
BT-74	819 in^2	5.69	ft^2
BT-72	767 in^2	5.33	ft^2
BT-63	713 in^2	4.95	ft^2
BT-54	659 in^2	4.58	ft^2
Type III	560 in^2	3.89	ft^2
Type II	369 in^2	2.56	ft^2
Type I Mod	332 in^2	2.31	ft^2

Wind: Greater of 50 psf and 300 plf minimum.

50 psf =	263	plf
Minimum Load =	300	plf
USE =	**300**	**plf**
Total Wind Load =	38.9	k
Half Wind to Diaphragm =	19.43	k

Provide tie downs at ends of girders

Diaphragm Load Top =	**9.71**	**k**
Diaphragm Load Bottom =	**9.71**	**k**

Check KL/r:

L3 x 3 x 7/16

r z =	0.585	in
k =	1.0	pin - pin
L =	56.5	in = 7'-5 1/2" max
kL/r =	96.58	**kL/r < 140**

OK

129.5'(0.3 klf) = 38.85k
/ 2
= 19.43k

= 19.43k/2

DATE: 07-Mar-2018

Approved in general. Details not checked. This approval shall not relieve the Contractor of any responsibility for conformity with the contract Plans and Specifications.

Georgia DOT
Office of Bridge Design
By: EMH

DATE: 07-Mar-2018

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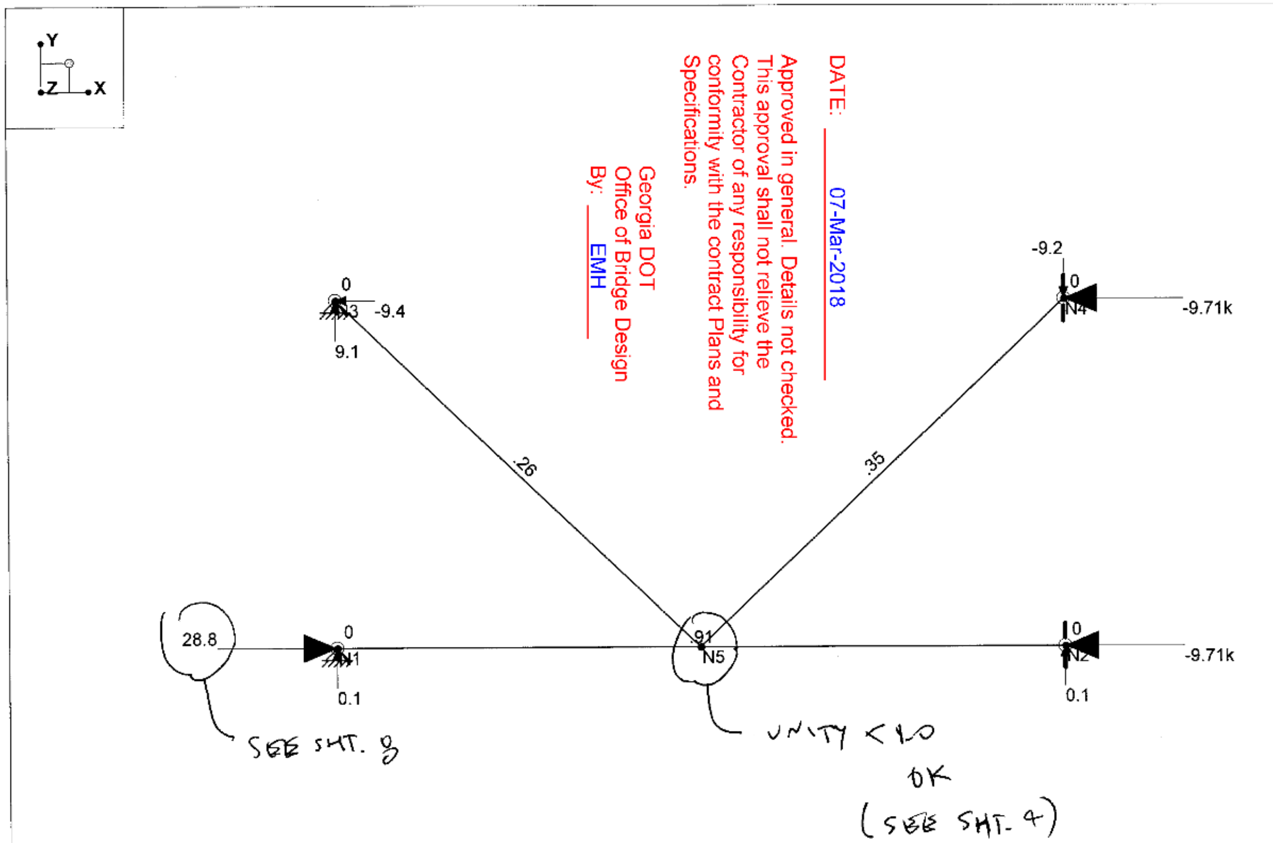
Georgia DOT
Office of Bridge Design
By: EMH



Member Code Checks Displayed
Loads: BLC 1,
Results for LC 1, Serv
Reaction and Moment Units are k and k-ft

	I-16/75 Br 10 - Spans 2-8	SK - 1
	Loads, Reactions and Unity	dia.r3d

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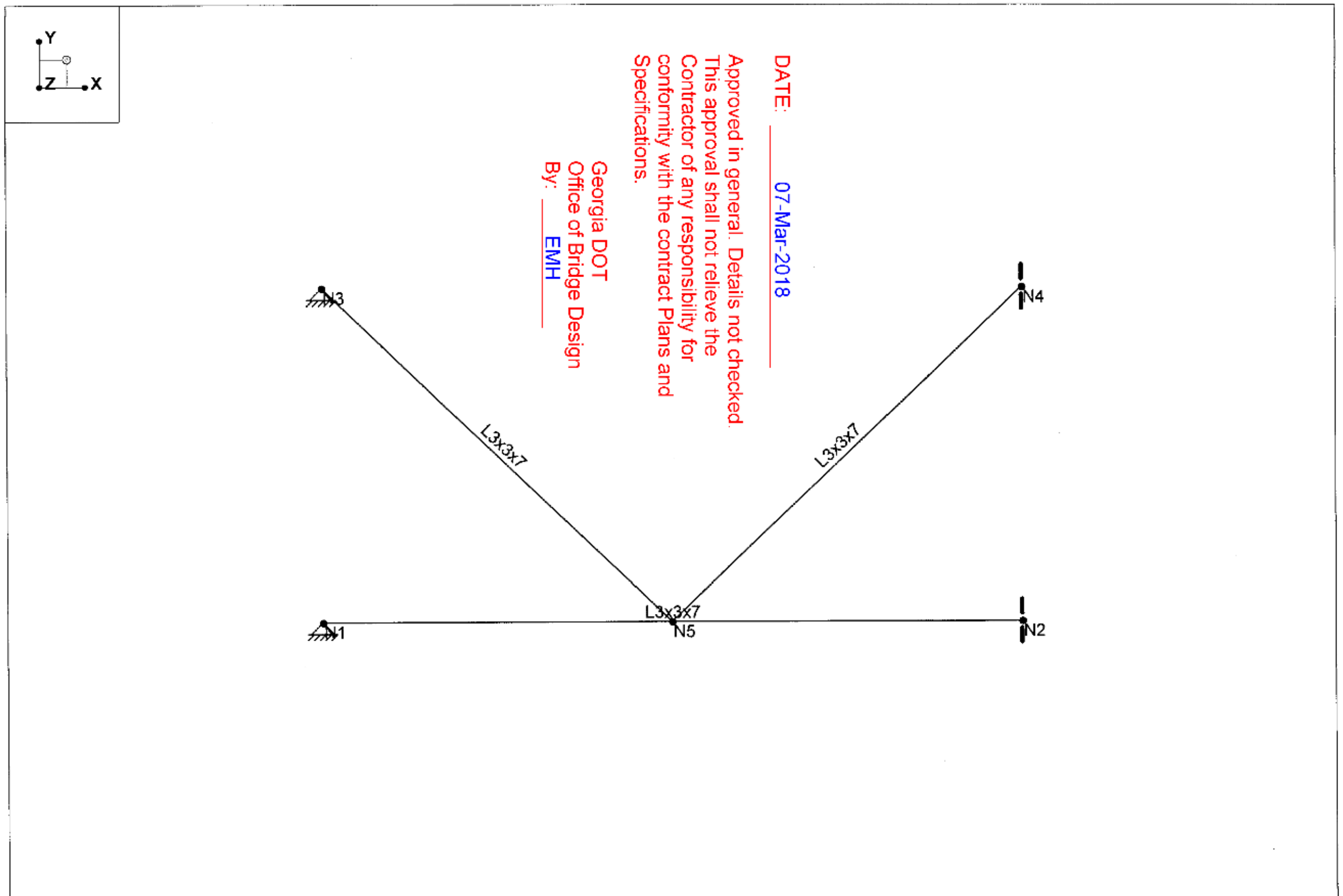
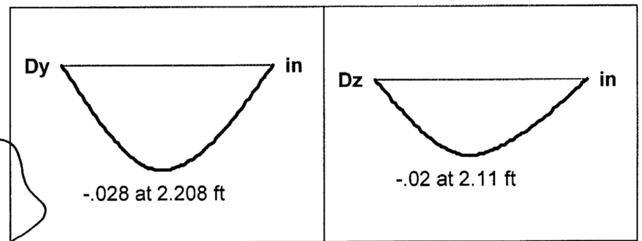


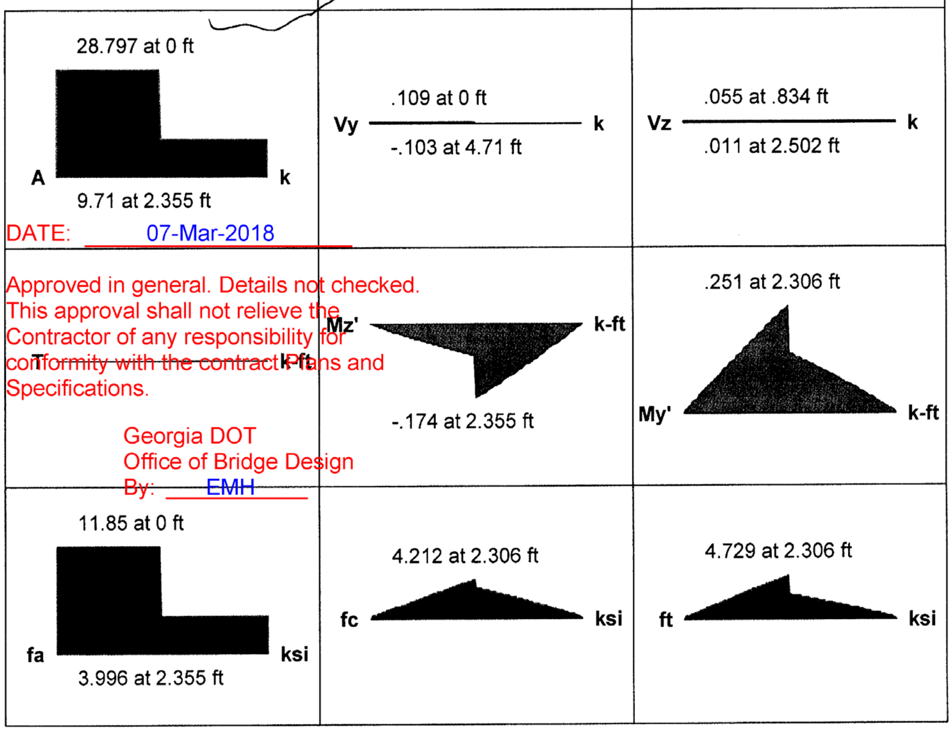
	I-16/75 Br 10 - Spans 2-8	SK - 2
	Shapes	dia.r3d

13

Beam: ***M1***

Shape: **L3x3x7**
Material: **A572 Gr.50**
Length: **4.71 ft**
I Joint: **N1**
J Joint: **N2**
LC 1: Serv
Code Check: **0.911 (bending)**
Report Based On 97 Sections





DATE: 07-Mar-2018

Approved in general. Details not checked.
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Georgia DOT
Office of Bridge Design
By: EMH

AISC 14th(360-10): ASD Code Check

Direct Analysis Method

Max Bending Check	**0.911**	Max Shear Check	**0.005 (y)**	Max Defl Ratio	**L/2000**
Location	**2.306 ft**	Location	**0 ft**	Location	**2.208 ft**
Equation	**H2-1**			Span	**1**

Bending Flange	**Compact**	Compression Flange	**Non-Slender**
Bending Web	**Compact**	Compression Web	**Non-Slender**

Fy	**50 ksi**
Pnc/om	**36.334 k**
Pnt/om	**72.754 k**
Mny'/om	**2.385 k-ft**
Mnz'/om	**5.544 k-ft**
Vny/om	**23.578 k**
Vnz/om	**23.578 k**
Cb	**1.423**

	y-y'	z-z'
Lb	**4.71 ft**	**4.71 ft**
KL/r	**97.448**	**49.701**

L Comp Flange	**4.71 ft**
L-torque	**4.71 ft**
Tau_b	**1**

4

5

(Global) Model Settings

Display Sections for Member Calcs	5
Max Internal Sections for Member Calcs	97
Include Shear Deformation?	Yes
Increase Nailing Capacity for Wind?	Yes
Include Warping?	Yes
Trans Load Btwn Intersecting Wood Wall?	Yes
Area Load Mesh (in^2)	144
Merge Tolerance (in)	.12
P-Delta Analysis Tolerance	0.50%
Include P-Delta for Walls?	Yes
Automatically Iterate Stiffness for Walls?	Yes
Max Iterations for Wall Stiffness	3
Gravity Acceleration (ft/sec^2)	32.2
Wall Mesh Size (in)	24
Eigensolution Convergence Tol. (1.E-)	4
Vertical Axis	Y
Global Member Orientation Plane	XZ
Static Solver	Sparse Accelerated
Dynamic Solver	Accelerated Solver

Hot Rolled Steel Code	AISC 14th(360-10): ASD
Adjust Stiffness?	Yes(Iterative)
RISAConnection Code	AISC 14th(360-10): ASD
Cold Formed Steel Code	AISI S100-12: ASD
Wood Code	AWC NDS-12: ASD
Wood Temperature	< 100F
Concrete Code	ACI 318-11
Masonry Code	ACI 530-13: ASD
Aluminum Code	AA ADM1-10: ASD - Building
	AISC 14th(360-10): ASD

Number of Shear Regions	4
Region Spacing Increment (in)	4
Biaxial Column Method	Exact Integration
Parme Beta Factor (PCA)	.65
Concrete Stress Block	Rectangular
Use Cracked Sections?	Yes
Use Cracked Sections Slab?	Yes
Bad Framing Warnings?	No
Unused Force Warnings?	Yes
Min 1 Bar Diam. Spacing?	No
Concrete Rebar Set	REBAR_SET_ASTMA615
Min % Steel for Column	1
Max % Steel for Column	8

DATE: 07-Mar-2018

Approved in general. Details not checked. This approval shall not relieve the Contractor of any responsibility for conformity with the contract Plans and Specifications.

Georgia DOT
Office of Bridge Design
By: EMH

6/

(Global) Model Settings, Continued

Seismic Code	ASCE 7-10
Seismic Base Elevation (ft)	Not Entered
Add Base Weight?	Yes
Ct X	.02
Ct Z	.02
T X (sec)	Not Entered
T Z (sec)	Not Entered
R X	3
R Z	3
Ct Exp. X	.75
Ct Exp. Z	.75
SD1	1
SDS	1
S1	1
TL (sec)	5
Risk Cat	I or II
Drift Cat	Other
Om Z	1
Om X	1
Cd Z	1
Cd X	1
Rho Z	1
Rho X	1

DATE: 07-Mar-2018

Approved in general. Details not checked. This approval shall not relieve the Contractor of any responsibility for conformity with the contract Plans and Specifications.

Georgia DOT
Office of Bridge Design
By: EMH

Hot Rolled Steel Properties

	Label	E [ksi]	G [ksi]	Nu	Therm (\1E...	Density[k/ft...	Yield[ksi]	Ry	Fu[ksi]	Rt
1	A992	29000	11154	.3	.65	.49	50	1.1	65	1.1
2	A36 Gr.36	29000	11154	.3	.65	.49	36	1.5	58	1.2
3	A572 Gr.50	29000	11154	.3	.65	.49	50	1.1	65	1.1
4	A500 Gr.B RND	29000	11154	.3	.65	.527	42	1.4	58	1.3
5	A500 Gr.B Rect	29000	11154	.3	.65	.527	46	1.4	58	1.3
6	A53 Gr.B	29000	11154	.3	.65	.49	35	1.6	60	1.2
7	A1085	29000	11154	.3	.65	.49	50	1.4	65	1.3

Hot Rolled Steel Section Sets

	Label	Shape	Type	Design List	Material	Design Rules	A [in2]	Iyy [in4]	Izz [in4]	J [in4]
1	L4x3	L3x3x7	Beam	Single Angle	A572 Gr.50	Typical	2.43	1.98	1.98	.157

Joint Coordinates and Temperatures

	Label	X [ft]	Y [ft]	Z [ft]	Temp [F]	Detach From Diap...
1	N1	0	0	0	0	
2	N2	4.71	0	0	0	
3	N3	0	2.25	0	0	
4	N4	4.71	2.25	0	0	
5	N5	2.35	0	0	0	

Joint Boundary Conditions

	Joint Label	X [k/in]	Y [k/in]	Z [k/in]	X Rot.[k-ft/rad]	Y Rot.[k-ft/rad]	Z Rot.[k-ft/rad]
1	N3	Reaction	Reaction	Reaction			
2	N1	Reaction	Reaction	Reaction			
3	N4		Reaction	Reaction			
4	N2		Reaction	Reaction			

Member Primary Data

	Label	I Joint	J Joint	K Joint	Rotate(deg)	Section/Shape	Type	Design List	Material	Design Rules
1	M1	N1	N2			L4x3	Beam	Single Angle	A572 Gr.50	Typical
2	M2	N3	N5			L4x3	Beam	Single Angle	A572 Gr.50	Typical
3	M3	N4	N5			L4x3	Beam	Single Angle	A572 Gr.50	Typical

Member Advanced Data

	Label	I Release	J Release	I Offset[in]	J Offset[in]	T/C Only	Physical	Analysis ...	Inactive	Seismic Design ...
1	M1						Yes			None
2	M2						Yes			None
3	M3						Yes			None

Hot Rolled Steel Design Parameters

	Label	Shape	Length[ft]	Lbyy[ft]	Lbzz[ft]	Lcomp top[ft]	Lcomp bot[ft]	L-torqu...	Kyy	Kzz	Cb	Function
1	M1	L4x3	4.71			Lbyy						Lateral
2	M2	L4x3	3.253			Lbyy						Lateral
3	M3	L4x3	3.261			Lbyy						Lateral

Joint Loads and Enforced Displacements (BLC 1 :)

	Joint Label	L,D,M	Direction	Magnitude[(k,k-ft), (in,rad), (k*s^2/ft...
1	N4	L	X	-9.71
2	N2	L	X	-9.71

Member Distributed Loads

Member Label	Direction	Start Magnitude[k/ft,...	End Magnitude[k/ft,F,...	Start Location[ft,%]	End Location[ft,%]
No Data to Print ...					

Basic Load Cases

	BLC Description	Category	X Gravity	Y Gravity	Z Gravity	Joint	Point	Distributed	Area(Me...	Surface(P...
1		None				2				

Moving Loads

Tag	Pattern	Increme...	Both ...	1st Joint	2nd Joint	3rd Joint	4th Joint	5th Joint	6th Joint	7th Joint	8th Joint	9th Joint	10th Joint
No Data to Print ...													

Load Combinations

DATE: 07-Mar-2018

	Description	Sol...	PD...	SR...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...
1	Serv	Yes	Y		Y	-1	1	1																

Approved in general. Details not checked.
This approval shall not relieve the Contractor of any responsibility for conformity with the contract Plans and Specifications.

Georgia DOT
Office of Bridge Design
By: EMH

SUBJECT:

BOLTS

2 - 7/8" ø A325/A449

AASHTO 17TH TABLE 10.32.3B

$F_v = 19$ ksi → THREADS INCL.

$A_{REBAR\ \frac{7}{8}"ø} = 0.6013\ in^2$

$P_S = 0.6013\ in^2 (2\ bolts)(19\ ksi)$

$= 22.8^k$

THREADS EXCLUDED:

$P_{EXCL} = 22.8^k (1.25) = 28.6^k \approx 28.8^k$

NOTE f ↑

OK

DATE: 07-Mar-2018

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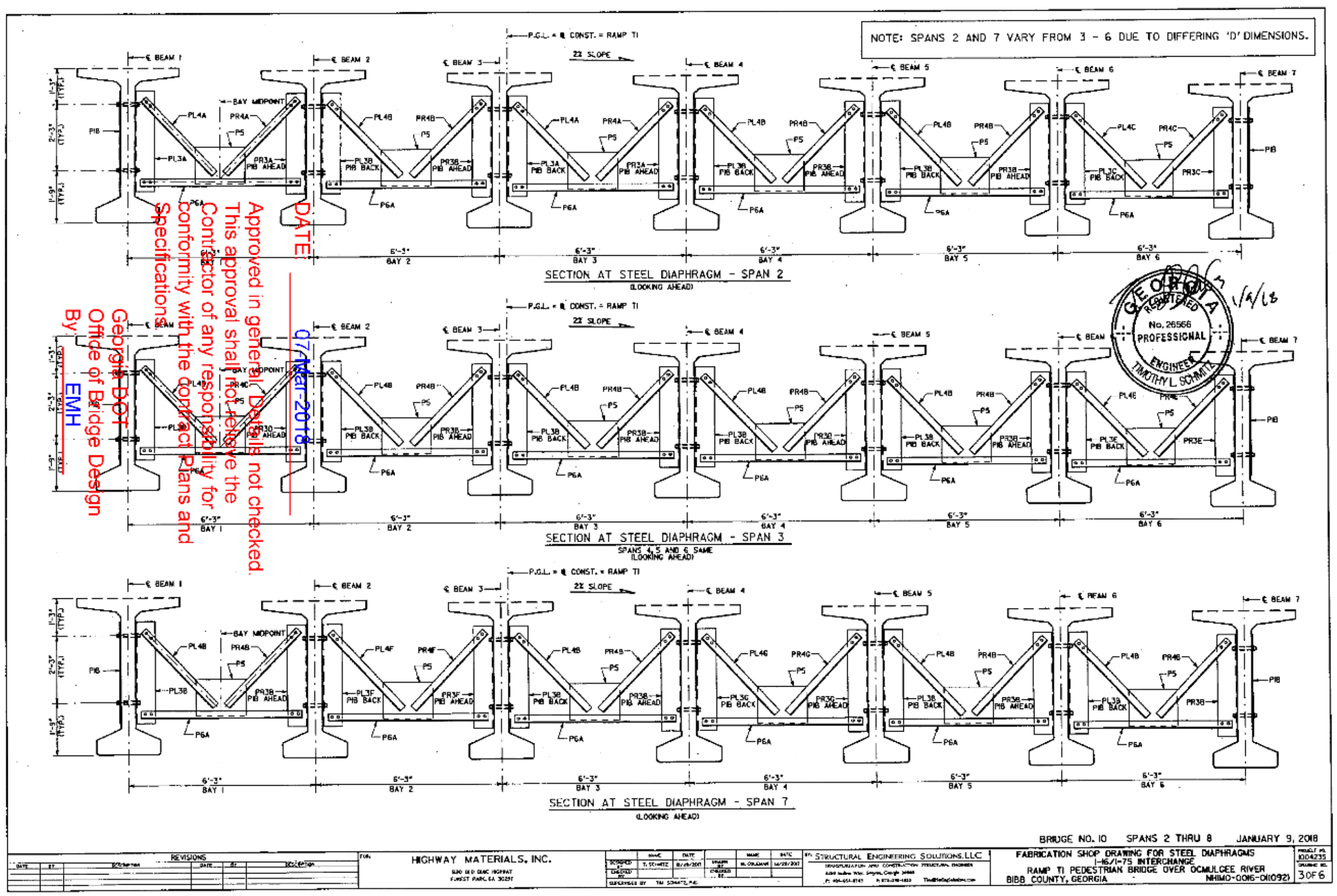
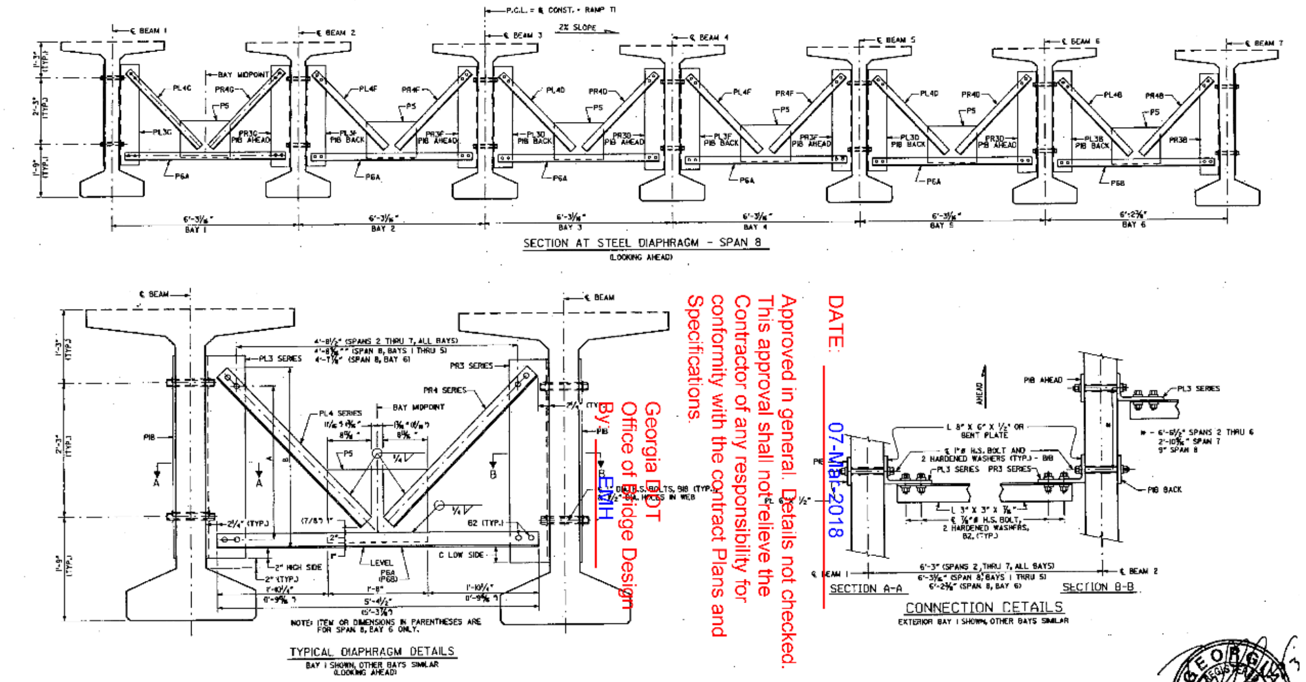
Georgia DOT
Office of Bridge Design
By: EMH


NOTE: SPANS 2 AND 7 VARY FROM 3 - 6 DUE TO DIFFERING 'D' DIMENSIONS.
SECTION AT STEEL DIAPHRAGM - SPAN 2
(LOOKING AHEAD)
SECTION AT STEEL DIAPHRAGM - SPAN 3
SPANS 4, 5 AND 6 SAME
(LOOKING AHEAD)
SECTION AT STEEL DIAPHRAGM - SPAN 7
(LOOKING AHEAD)
DATE: 07-Mar-2018
Approved in general. Details not checked.
This approval shall not relieve the
Contractor of any responsibility for
conformity with the contract Plans and
Specifications.
Georgia DOT
Office of Bridge Design
By EMH
GEORGIA
REGISTERED
No. 26566
PROFESSIONAL
ENGINEER
TIMOTHY L. SCHMITZ
1/9/18
BRIDGE NO. 10 SPANS 2 THRU 8 JANUARY 9, 2018
HIGHWAY MATERIALS, INC.
STRUCTURAL ENGINEERING SOLUTIONS, LLC
FABRICATION SHOP DRAWING FOR STEEL DIAPHRAGMS
I-16/I-75 INTERCHANGE
RAMP T1 PEDESTRIAN BRIDGE OVER OCMULGEE RIVER
BIBB COUNTY, GEORGIA
NHIMO-0016-01(092)
3 OF 6



DATE: 07-Mar-2018

Approved in general. Details not checked. This approval shall not relieve the Contractor of any responsibility for conformity with the contract Plans and Specifications.

Georgia DOT
Office of Bridge Design
By: EMH

TABLE OF LETTERED DIMENSIONS

LETTER	SPAN 2						SPAN 3 (SPANS 4 THRU 6 SAME)					
	BAY 1	BAY 2	BAY 3	BAY 4	BAY 5	BAY 6	BAY 1	BAY 2	BAY 3	BAY 4	BAY 5	BAY 6
A	2'-7"	2'-6¾"	2'-7"	2'-6¾"	2'-6¾"	2'-6¼"	2'-7⅛"	2'-6¾"	2'-6¾"	2'-6¾"	2'-6¾"	2'-6⅜"
B	3'-0½"	3'-0¼"	3'-0½"	3'-0¼"	3'-0¼"	2'-11¾"	3'-0⅝"	3'-0¼"	3'-0¼"	3'-0¼"	3'-0¼"	2'-11⅞"
C	3¼"	3½"	3¼"	3½"	3½"	4"	3⅛"	3½"	3½"	3½"	3½"	3⅞"

SPAN 7						SPAN 8						LETTER
BAY 1	BAY 2	BAY 3	BAY 4	BAY 5	BAY 6	BAY 1	BAY 2	BAY 3	BAY 4	BAY 5	BAY 6	
2'-6¾"	2'-7¼"	2'-6¾"	2'-7½"	2'-6¾"	2'-6¾"	2'-7½"	2'-7¼"	2'-7⅛"	2'-7¼"	2'-7⅛"	2'-6¾"	A
3'-0¼"	3'-0¾"	3'-0¼"	3'-1"	3'-0¼"	3'-0¼"	3'-1"	3'-0¾"	3'-0⅝"	3'-0¾"	3'-0⅝"	3'-0¼"	B
3½"	3"	3½"	2¾"	3½"	3½"	2¾"	3"	3⅛"	3"	3⅛"	3½"	C

BRIDGE NO. 10 SPANS 2 THRU 8 JANUARY 9, 2018

REVISIONS

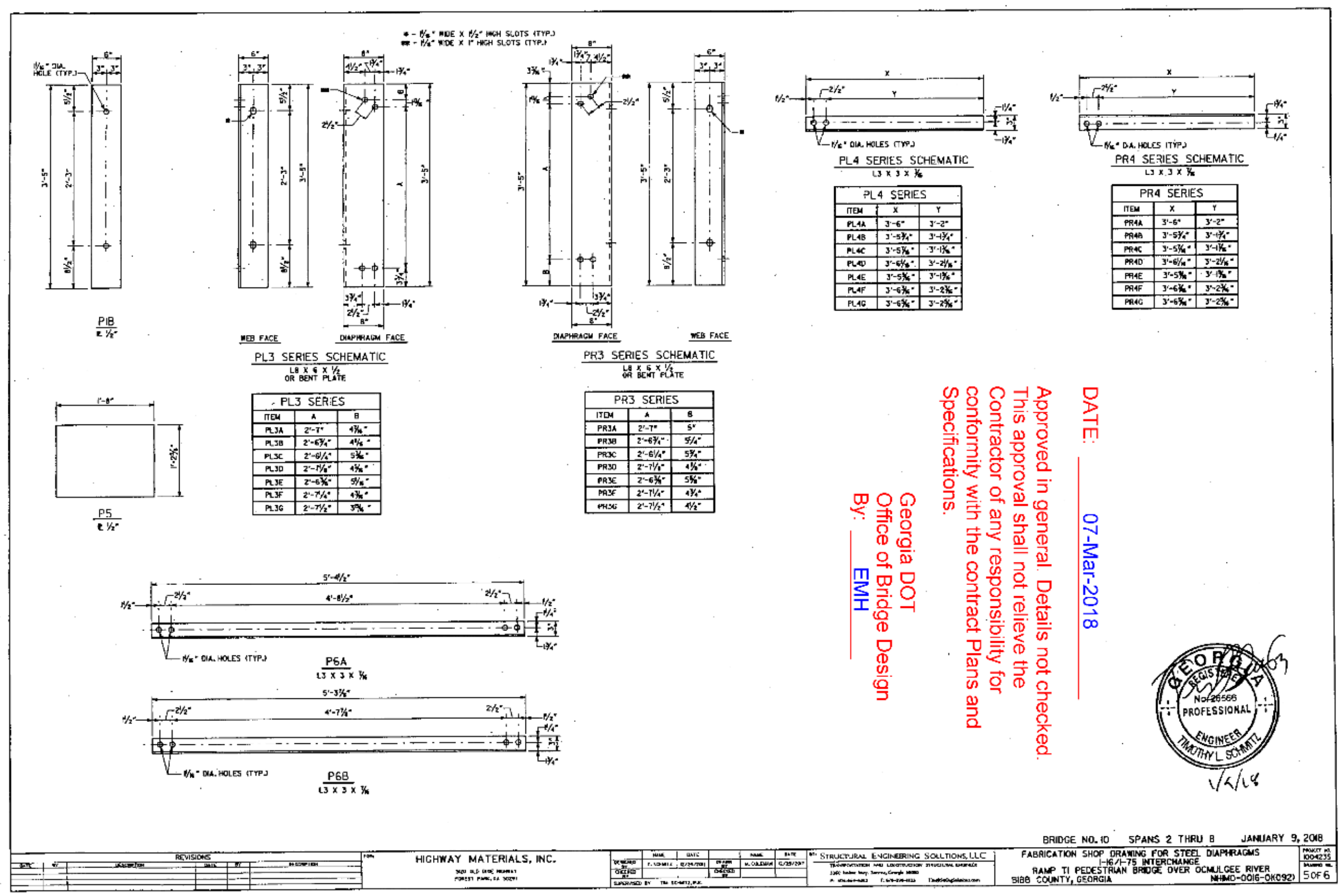
HIGHWAY MATERIALS, INC.
500 OLD DIXIE HIGHWAY
FOREST PARK, GA 30297

DESIGNED BY T. SCHMITZ 12/29/2017 | DRAWN BY M. SOLEIMAN 12/29/2017 | SUPERVISED BY TIM SCHMITZ, P.E.

STRUCTURAL ENGINEERING SOLUTIONS, LLC
TRANSPORTATION AND CONSTRUCTION STRUCTURAL ANALYSIS

FABRICATION SHOP DRAWING FOR STEEL DIAPHRAGMS
I-16/I-75 INTERCHANGE
RAMP T1 PEDESTRIAN BRIDGE OVER OCMULGEE RIVER
BIBB COUNTY, GEORGIA
NHIMO-0016-01(092)
4 OF 6

GEORGIA REG. No. 26566 PROFESSIONAL ENGINEER TIMOTHY L. SCHMITZ
1/9/18



PL3 SERIES		
ITEM	A	B
PL3A	2'-7"	4 3/16"
PL3B	2'-6 3/4"	4 1/16"
PL3C	2'-6 1/4"	5 3/16"
PL3D	2'-7 1/8"	4 5/16"
PL3E	2'-6 3/8"	5 1/16"
PL3F	2'-7 1/4"	4 3/16"
PL3G	2'-7 1/2"	3 15/16"

PR3 SERIES		
ITEM	A	B
PR3A	2'-7"	5"
PR3B	2'-6 3/4"	5 1/4"
PR3C	2'-6 1/4"	5 3/4"
PR3D	2'-7 1/8"	4 1/8"
PR3E	2'-6 3/8"	5 5/8"
PR3F	2'-7 1/4"	4 3/4"
PR3G	2'-7 1/2"	4 1/2"

PL4 SERIES		
ITEM	X	Y
PL4A	3'-6"	3'-2"
PL4B	3'-5 3/4"	3'-1 3/4"
PL4C	3'-5 7/8"	3'-1 7/8"
PL4D	3'-6 1/16"	3'-2 1/16"
PL4E	3'-5 5/16"	3'-1 5/16"
PL4F	3'-6 3/16"	3'-2 3/16"
PL4G	3'-6 5/16"	3'-2 5/16"

PR4 SERIES		
ITEM	X	Y
PR4A	3'-6"	3'-2"
PR4B	3'-5 3/4"	3'-1 3/4"
PR4C	3'-5 7/8"	3'-1 7/8"
PR4D	3'-6 1/16"	3'-2 1/16"
PR4E	3'-5 5/16"	3'-1 5/16"
PR4F	3'-6 3/16"	3'-2 3/16"
PR4G	3'-6 5/16"	3'-2 5/16"

DATE: 07-Mar-2018

Approved in general. Details not checked. This approval shall not relieve the Contractor of any responsibility for conformity with the contract Plans and Specifications.

Georgia DOT
Office of Bridge Design
By: EMH

BILL OF MATERIALS FOR ONE SPAN.

BILL OF MATERIAL - SPAN 2

MARK	QTY.	DESCRIPTION	FT	IN	16TH	FAB MARK	MILL MARK	WEIGHT
SP 2						TOTAL WT = 2227 LBS		
	12	PL 6 X ½	3	5	0	P1B		419
	2	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3A		157
	3	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3B		236
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3C		79
	2	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3A		157
	3	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3B		236
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3C		79
	2	L 3 X 3 X 5/16	3	6	0	PL4A		59
	3	L 3 X 3 X 5/16	3	5	12	PL4B		87
	1	L 3 X 3 X 5/16	3	5	7	PL4C		29
	2	L 3 X 3 X 5/16	3	6	0	PR4A		59
	3	L 3 X 3 X 5/16	3	5	12	PR4B		87
	1	L 3 X 3 X 5/16	3	5	7	PR4C		29
	6	PL 14⅝ X ½	1	8	0	P5		249
	6	L 3 X 3 X 5/16	5	4	8	P6A		268
	24	1"φ A449 BOLT, NUT AND WASHERS	0	10	8	B1B		
	48	7/8"φ A449 BOLT, NUT AND WASHERS	0	3	8	B2		

BILL OF MATERIAL FOR ONE SPAN. PROVIDE SPAN QUANTITIES X 4 FOR TOTAL.

BILL OF MATERIAL - SPAN 3 (SPANS 4 THRU 6 SAME)

MARK	QTY.	DESCRIPTION	FT	IN	16TH	FAB MARK	MILL MARK	WEIGHT
SP 3						TOTAL WT = 2227 LBS		
	12	PL 6 X ½	3	5	0	P1B		419
	4	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3B		314
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3D		79
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3E		79
	4	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3B		314
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3D		79
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3E		79
	4	L 3 X 3 X 5/16	3	5	12	PL4B		116
	1	L 3 X 3 X 5/16	3	6	1	PL4D		29
	1	L 3 X 3 X 5/16	3	5	9	PL4E		29
	4	L 3 X 3 X 5/16	3	5	12	PR4B		116
	1	L 3 X 3 X 5/16	3	6	1	PR4D		29
	1	L 3 X 3 X 5/16	3	5	9	PR4E		29
	6	PL 14⅝ X ½	1	8	0	P5		249
	6	L 3 X 3 X 5/16	5	4	8	P6A		268
	24	1"φ A449 BOLT, NUT AND WASHERS	0	10	8	B1B		
	48	7/8"φ A449 BOLT, NUT AND WASHERS	0	3	8	B2		

BILL OF MATERIALS FOR ONE SPAN.

BILL OF MATERIAL - SPAN 7

MARK	QTY.	DESCRIPTION	FT	IN	16TH	FAB MARK	MILL MARK	WEIGHT
SP 7						TOTAL WT = 2226 LBS		
	12	PL 6 X ½	3	5	0	P1B		419
	4	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3B		314
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3F		79
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3G		79
	4	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3B		314
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3F		79
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3G		79
	4	L 3 X 3 X 5/16	3	5	12	PL4B		116
	1	L 3 X 3 X 5/16	3	6	3	PL4F		29
	1	L 3 X 3 X 5/16	3	6	5	PL4G		29
	4	L 3 X 3 X 5/16	3	5	12	PR4B		116
	1	L 3 X 3 X 5/16	3	6	3	PR4F		29
	1	L 3 X 3 X 5/16	3	6	5	PR4G		29
	6	PL 14⅝ X ½	1	8	0	P5		249
	6	L 3 X 3 X 5/16	5	4	8	P6A		268
	24	1"φ A449 BOLT, NUT AND WASHERS	0	10	8	B1B		
	48	7/8"φ A449 BOLT, NUT AND WASHERS	0	3	8	B2		

BILL OF MATERIALS FOR ONE SPAN.

BILL OF MATERIAL - SPAN 8

MARK	QTY.	DESCRIPTION	FT	IN	16TH	FAB MARK	MILL MARK	WEIGHT
SP 8						TOTAL WT = 2228 LBS		
	12	PL 6 X ½	3	5	0	P1B		419
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3B		79
	2	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3D		157
	2	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3F		157
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3G		79
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3B		79
	2	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3D		157
	2	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3F		157
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3G		79
	1	L 3 X 3 X 5/16	3	5	12	PL4B		29
	2	L 3 X 3 X 5/16	3	6	1	PL4D		58
	2	L 3 X 3 X 5/16	3	6	3	PL4F		58
	1	L 3 X 3 X 5/16	3	6	5	PL4G		29
	1	L 3 X 3 X 5/16	3	5	12	PR4B		29
	2	L 3 X 3 X 5/16	3	6	1	PR4D		58
	2	L 3 X 3 X 5/16	3	6	3	PR4F		58
	1	L 3 X 3 X 5/16	3	6	5	PR4G		29
	6	PL 14⅝ X ½	1	8	0	P5		249
	5	L 3 X 3 X 5/16	5	4	8	P6A		223
	1	L 3 X 3 X 5/16	5	3	14	P6B		45
	24	1"φ A449 BOLT, NUT AND WASHERS	0	10	8	B1B		
	48	7/8"φ A449 BOLT, NUT AND WASHERS	0	3	8	B2		

BILL OF MATERIAL - TOTAL FOR SPANS 1 THRU 8

MARK	QTY.	DESCRIPTION	FT	IN	16TH	FAB MARK	MILL MARK	WEIGHT
SP 1-8						TOTAL WT = 17,516 LBS		
	12	PL 6 X ½	1	6	0	PA		184
	84	PL 6 X ½	3	5	0	PB		2933
	8	L 6 X 6 X ½ OR EQUIV. BENT PL	1	6	0	P2A		236
	4	6"X 10½" X ½" BENT PL	1	10	0	P2B		200
	2	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3A		157
	24	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3B		1885
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3C		79
	6	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3D		473
	4	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3E		316
	3	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3F		236
	2	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PL3G		158
	2	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3A		157
	24	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3B		1885
	1	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3C		79
	6	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3D		473
	4	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3E		316
	3	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3F		236
	2	L 8 X 6 X ½ OR EQUIV BENT PL	3	5	0	PR3G		157
	2	L 3 X 3 X 5/16	3	6	0	PL4A		58
	24	L 3 X 3 X 5/16	3	5	12	PL4B		693
	1	L 3 X 3 X 5/16	3	5	7	PL4C		29
	6	L 3 X 3 X 5/16	3	6	1	PL4D		175
	4	L 3 X 3 X 5/16	3	5	9	PL4E		115
	3	L 3 X 3 X 5/16	3	6	3	PL4F		88
	2	L 3 X 3 X 5/16	3	6	5	PL4G		59
	2	L 3 X 3 X 5/16	3	6	0	PR4A		58
	24	L 3 X 3 X 5/16	3	5	12	PR4B		693
	1	L 3 X 3 X 5/16	3	5	7	PR4C		29
	6	L 3 X 3 X 5/16	3	6	1	PR4D		175
	4	L 3 X 3 X 5/16	3	5	9	PR4E		116
	3	L 3 X 3 X 5/16	3	6	3	PR4F		88
	2	L 3 X 3 X 5/16	3	6	5	PR4G		59

BILL OF MATERIAL - TOTAL FOR SPANS 1 THRU 8 (CONT.)

MARK	QTY.	DESCRIPTION	FT	IN	16TH	FAB MARK	MILL MARK	WEIGHT
SP 1-8						TOTAL WT = 17,516 LBS		
	42	PL 14⅝ X ½	1	8	0	P5		1743
	41	L 3 X 3 X 5/16	5	4	8	P6A		1831
	1	L 3 X 3 X 5/16	5	3	14	P6B		45
	2	MC 18 X 42.7	5	4	8	C1A		459
	4	MC 18 X 42.7	4	11	12	C1B		850
	24	1"φ A449 BOLT, NUT AND WASHERS	0	10	8	DIA		
	168	1"φ A449 BOLT, NUT AND WASHERS	0	10	8	B1B		
[1]	384	7/8"φ A449 BOLT, NUT AND WASHERS	0	3	8	92		

[1] - PROVIDE TWO HARDENED WASHERS AND ONE DIRECT TENSION INDICATOR (DTI) WASHER FOR EACH BOLT (48) IN SPAN 1.

NOTES:

1. ALL STEEL SHALL BE ASTM A709, GR. 50.
2. ALL BOLTS SHALL BE ASTM A325 OR A449, WITH ASTM A563 HEAVY HEX NUTS AND ASTM F436 HARDENED WASHER UNDER EACH BOLT HEAD AND NUT.
3. ALL BOLTS SHALL BE TIGHTENED IN ACCORDANCE WITH SECTION 501 OF THE GEORGIA SPECIFICATION. IN ABSENCE OF SPECIFICATIONS FOR DTI WASHERS, CONTRACTOR SHALL VERIFY DTI WITH GDOT SPECIFICATIONS APPROVED BOLT TIGHTENING PROCEDURE.
4. ALL STRUCTURAL STEEL MATERIALS INCLUDING BOLTS, NUTS AND WASHERS SHALL BE HOT DIPPED GALVANIZED IN ACCORDANCE WITH ASTM A-123 OR A-153.
5. INTERMEDIATE DIAPHRAGM ASSEMBLY SHALL COMPLY WITH SECTION 851 OF THE GEORGIA STANDARD SPECIFICATIONS.
6. VERIFY BOLT SPACING IN GIRDERS WITH BEAM SHOP DRAWINGS.
7. PLACE AND FINGER TIGHTEN ALL BOLTS BEFORE FINAL TENSIONING. CONTRACTOR SHALL ANTICIPATE ADJUSTMENT OF BOLTS IN SLOTS TO FIT ALL BOLTS.
8. ALL FABRICATION IS TO BE PERFORMED BY HIGHWAY MATERIALS, INC., QPL NO. 59.
9. 1"φ BOLTS SHALL HAVE 3½" MINIMUM OF THREAD LENGTH.
10. AS A MINIMUM, THE STEEL CROSS-FRAMES ARE DESIGNED FOR THE LONG TERM WIND DESIGN LOADS INDUCED ON THE STRUCTURE. STABILITY OF THE PRESTRESSED BEAMS DURING ALL PHASES OF CONSTRUCTION SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR. THE CONTRACTOR SHALL PROVIDE ANY TEMPORARY BRACING OR SUPPORT NECESSARY TO ENSURE STABILITY OF THE STRUCTURE UNTIL CONSTRUCTION IS COMPLETE.

Approved in general. Details not checked. This approval shall not relieve the Contractor of any responsibility for conformance to the contract Plans and specifications.
DATE: 07 Mar 2018
By: EMH
Office of Bridge Design

GEORGIA No. 26566 PROFESSIONAL ENGINEER TIMOTHY L. SCHMITZ
1/9/18

BRIDGE NO. 10 SPANS 1 THRU 8 JANUARY 9, 2018

REVISIONS

DATE	BY	DESCRIPTION	DATE	BY	DESCRIPTION

HIGHWAY MATERIALS, INC.
5120 OLD DIXIE HIGHWAY
FOREST PARK, GA 30297

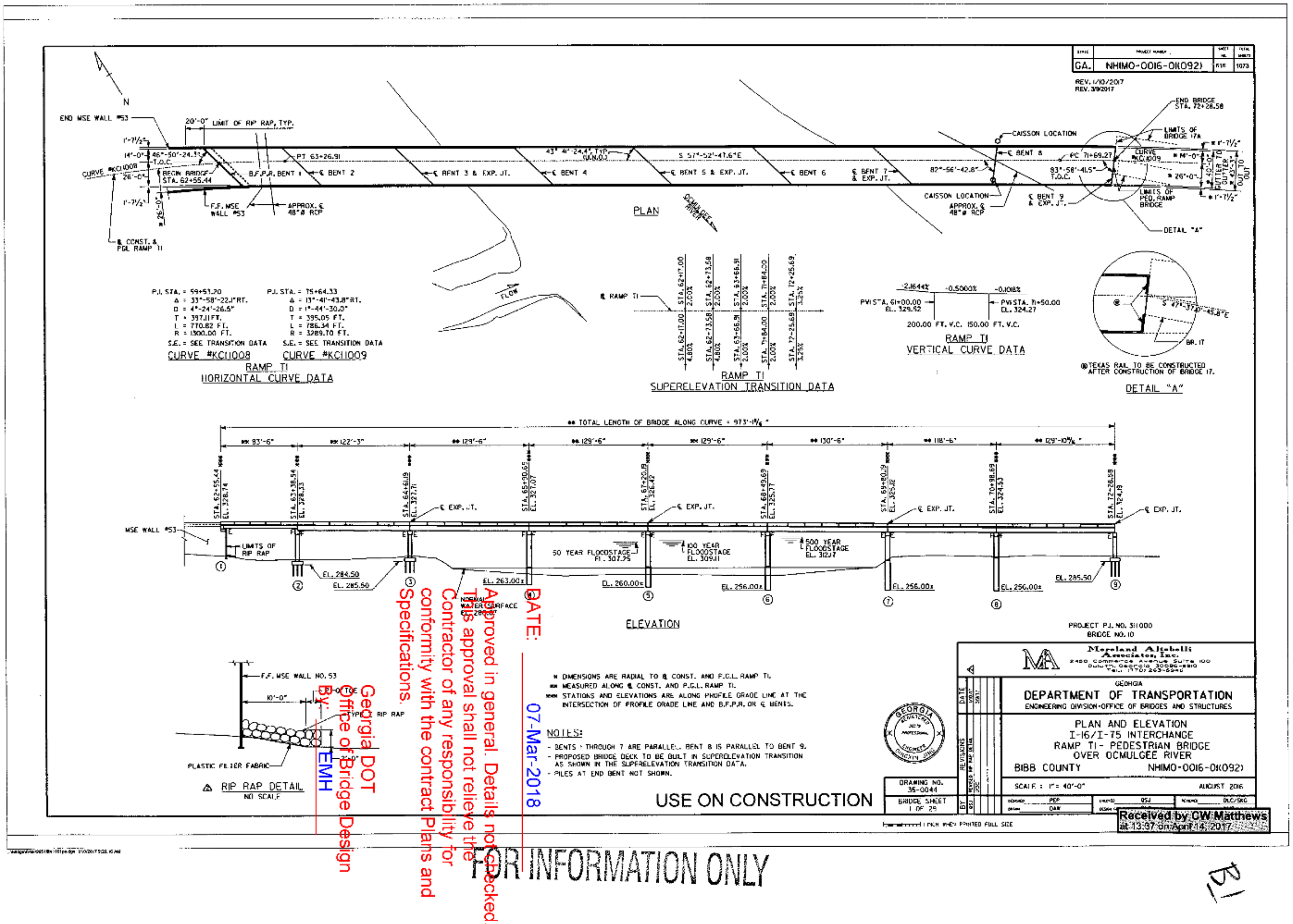
DESIGNED BY: T. SCHMITZ 12/24/2017 DRAWN BY: H. COLEMAN 12/28/2017
CHECKED BY: CHECKED BY:
SUPERVISED BY: TIM SCHMITZ, P.E.

STRUCTURAL ENGINEERING SOLUTIONS, LLC
TRANSPORTATION AND CONSTRUCTION STRUCTURAL ENGINEERING

FABRICATION SHOP DRAWING FOR STEEL DIAPHRAGMS
I-16/I-75 INTERCHANGE
RAMP 7I PEDESTRIAN BRIDGE OVER OCMULGEE RIVER
BIBB COUNTY, GEORGIA NHIMO-0016-01(092)

PROJECT NO. 1004235
DRAWING NO. 6 OF 6

1A



FOR INFORMATION ONLY

B1

STATE	PROJECT NUMBER	SHEET NO.	TOTAL SHEETS
GA.	NHIMO-0016-01(092)	617	1073

REV. 11/16/2016
REV. 1/10/2017
REV. 3/9/2017

BRIDGE CONSISTS OF

1 - 83'-6" TYPE III PSC BEAM SPAN ---------- SPECIAL DESIGN
1 - 122'-3" BULB TEE, 63 IN, PSC BEAM SPAN ---------- SPECIAL DESIGN
3 - 129'-6" BULB TEE, 63 IN, PSC BEAM SPANS ---------- SPECIAL DESIGN
1 - 130'-6" BULB TEE, 63 IN, PSC BEAM SPAN ---------- SPECIAL DESIGN
1 - 118'-6" BULB TEE, 63 IN, PSC BEAM SPAN ---------- SPECIAL DESIGN
1 - 129'-10 11/16 " BULB TEE, 63 IN, PSC BEAM SPAN ---------- SPECIAL DESIGN
1 - STEEL H PILE END BENT WITH MSE ABUTMENT ---------- SPECIAL DESIGN
8 - CONCRETE INTERMEDIATE BENTS ---------- SPECIAL DESIGN
BAR BENDING DETAILS ---------- GA. STD. 3901 (8-69)
TYPICAL FILL DETAIL AT END OF BRIDGE ---------- GA. STD. 9037 (9-99)

DESIGN DATA

SPECIFICATIONS ---------- AASHTO 17TH EDITION, 2002
(DESIGNED FOR SEISMIC PERFORMANCE CATEGORY A)
TYPICAL HS20-44 AND/OR MILITARY LOADING ---------- IMPACT ALLOWED
FUTURE PAVING ALLOWANCE ---------- 30 LBS PER SQ FT
CONCRETE: SUPERSTRUCTURE ---------- CLASS AA, f'_c = 3,500 PSI
BARRIER ---------- CLASS AA, f'_c = 3,500 PSI
PSC BEAMS ---------- CLASS AAA, f'_c = SEE BEAM SHEETS
PSC BEAM ALLOWABLE TENSION ---------- SEE BEAM SHEETS
SUBSTRUCTURE ---------- CLASS AA, f'_c = 3,500 PSI
REINFORCEMENT STEEL: ---------- GRADE 60, f_y = 60,000 PSI
PRETENSIONING STRANDS: ---------- f_s = 270,000 PSI
STEEL H PILES: ---------- f_y = 36,000 PSI

TRAFFIC DATA

TRAFFIC ---------- ADT = 29,500 (2016)
ADT = 40,050 (2036)
DESIGN SPEED ---------- 45 MPH
TRUCKS ---------- 10%
24 HR TRUCKS ---------- 7%
DIRECTIONAL ---------- 100%

DRAINAGE DATA

DRAINAGE AREA ---------- 2,236 SQ MILES

FLOOD FREQUENCY	DISCHARGE	MEAN VELOCITY	AREA OF OPENING UNDER FLOODSTAGE	BACKWATER
50 YEAR	83,800 CFS	6.61 FPS	12,677 SQ FT	0.35 FT
100 YEAR	95,000 CFS	6.93 FPS	13,715 SQ FT	0.32 FT
500 YEAR	121,000 CFS	8.03 FPS	15,074 SQ FT	0.91 FT

GENERAL NOTES

SPECIFICATIONS - GEORGIA STANDARD SPECIFICATIONS, 2013 EDITION AS MODIFIED BY CONTRACT DOCUMENTS.

REINFORCING STEEL - PLACE AND TIE ALL REINFORCING STEEL IN ACCORDANCE WITH THE GEORGIA DOT SPECIFICATIONS. DO NOT WELD REINFORCING STEEL.

CHAMFER - CHAMFER ALL EXPOSED CONCRETE EDGES 3/4" UNLESS OTHERWISE NOTED.

WAITING PERIOD - DO NOT BEGIN WORK AT BENT 1 UNTIL THE COMPLETED END FILL HAS BEEN IN PLACE FOR AN ESTIMATED PERIOD OF 60 DAYS.

△

PLAN DRIVING OBJECTIVES - SEE SUBSTRUCTURE DETAILS.

△ ERRATIC PILE LENGTHS - ERRATIC PILE LENGTHS CAN BE EXPECTED.

△ PILOT HOLES - DRILL A 24" DIAMETER PILOT HOLE TO A MINIMUM ELEVATION OF 272.00 AT BENT 2 AND 273.00 AT BENT 3 FOR EACH PILE IF DIRECTED BY THE ENGINEER. FILL PILOT HOLES WITH CLASS A CONCRETE TO THE TOP OF THE ROCK AFTER THE PILES ARE DRIVEN. SEE SPECIAL PROVISION SECTION 520 FOR ADDITIONAL REQUIREMENTS.

DRIVING DATA PILES - ONE DRIVING DATA PILE SHALL BE REQUIRED AT EACH OF BENTS 1 & 9.

SMOOTH DOWEL BARS - PLACE SMOOTH DOWEL BARS IN FORMED 3" DIAMETER X 12" DEEP HOLES AND GROUT IN PLACE SIMILAR TO ANCHOR BOLTS. SEE SUB-SECTION 501.3.05.B.3 OF THE GEORGIA DOT SPECIFICATIONS. STIRRUPS MAY BE SHIFTED SLIGHTLY TO CLEAR FORMED HOLES.

ABUTMENT SOIL REINFORCING DEVICE INSERTS - INCLUDE THE COST OF FURNISHING AND INSTALLING INSERTS FOR SOIL REINFORCING DEVICES AT ABUTMENT 1 IN THE OVERALL BID SUBMITTED.

FILL SETTLEMENT - PROTECT PILES DRIVEN AT BENT 1 FROM NEGATIVE SKIN FRICTION WHEN USED IN CONJUNCTION WITH MECHANICALLY STABILIZED EARTH WALLS. SEE SECTION 551 OF THE GEORGIA DOT SPECIFICATIONS. DRIVE PILES AT END BENT BEFORE WALL LEVELING PADS ARE CONSTRUCTED.

GROOVED CONCRETE - GROOVE THE ENTIRE LENGTH OF THE BRIDGE TRANSVERSELY AS PER SUB-SECTION 500.3.05.T.9.C OF THE GEORGIA DOT SPECIFICATIONS.

WELDING - ALL WELDING ON GEORGIA DOT PROJECTS SHALL BE PERFORMED BY CERTIFIED WELDERS THAT HAVE IN THEIR POSSESSION A CURRENT WELDING CERTIFICATION CARD ISSUED BY THE OFFICE OF MATERIALS AND TESTING. USE ONLY E70XX (EXCLUDING E7014 AND E7024) LOW HYDROGEN ELECTRODES FOR MANUAL SHIELDED METAL ARC WELDING.

INCIDENTAL ITEMS - INCLUDE THE COST INCIDENTAL TO THE WORK THAT IS NOT SPECIFICALLY COVERED BY THE GEORGIA STANDARD SPECIFICATIONS, SUPPLEMENTAL SPECIFICATIONS AND/OR SPECIAL PROVISIONS IN THE OVERALL BID SUBMITTED. THIS INCLUDES THE COST OF WATERPROOFING, JOINT FILLERS, AND OTHER INCIDENTAL ITEMS NECESSARY TO COMPLETE THE WORK.

SUMMARY OF QUANTITIES

PAY ITEM NUMBER	QUANTITY	UNIT	PAY ITEM
211-0300	362	CY	BRIDGE EXCAVATION, STREAM CROSSING.
△ 449-1350	233	LF	PREFORMED SILICONE JOINT SEAL, BR NO - 10
500-0100	4109	SY	GROOVED CONCRETE
500-1006	LUMP	LS	SUPERSTR CONCRETE, CL AA, BR NO - 10 (1301)
500-2100	1935	LF	CONCRETE BARRIER
500-3002	984	CY	CLASS AA CONCRETE
507-9003	579	LF	PSC BEAMS, AASHTO TYPE III, BR NO - 10
507-9031	6076	LF	PSC BEAMS, AASHTO, BULB TEE, 63 IN, BR NO - 10
511-1000	175687	LB	BAR REINF STEEL
511-3000	LUMP	LS	SUPERSTR REINF STEEL, BR NO - 10 (282796)
520-1125	350	LF	PILING IN PLACE, STEEL H, HP 12 X 53
△ 520-1147	1190	LF	PILING IN PLACE, STEEL H, HP 14 X 73
520-4125	1	EA	LOAD TEST, STEEL H, HP 12 X 53 (IF REQ'D)
520-4147	1	EA	LOAD TEST, STEEL H, HP 14 X 73 (IF REQ'D)
△ 520-5000	600	LF	PILOT HOLES
524-0010	411	LF	DRILLED CAISSON - 66 IN
54[illegible]-1000	LUMP	LS	DECK DRAIN SYSTEM, BR NO - 10
△ 603-2024	202	SY	STN DUMPED RIP RAP, TP I, 24 IN.
△ 603-7000	202	SY	PLASTIC FILTER FABRIC

BRIDGE NO. 10

Moreland Altobelli Associates, Inc.
2450 Commerce Avenue Suite 100
Duluth, Georgia 30096-8910
Tel: (770) 263-5945

GEORGIA
DEPARTMENT OF TRANSPORTATION
ENGINEERING DIVISION-OFFICE OF BRIDGES AND STRUCTURES

GENERAL NOTES
I-16/I-75 INTERCHANGE
RAMP T1 - PEDESTRIAN BRIDGE
OVER OCMULGEE RIVER
BIBB COUNTY NHIMO-0016-01(092)

SCALE : NONE AUGUST 2016

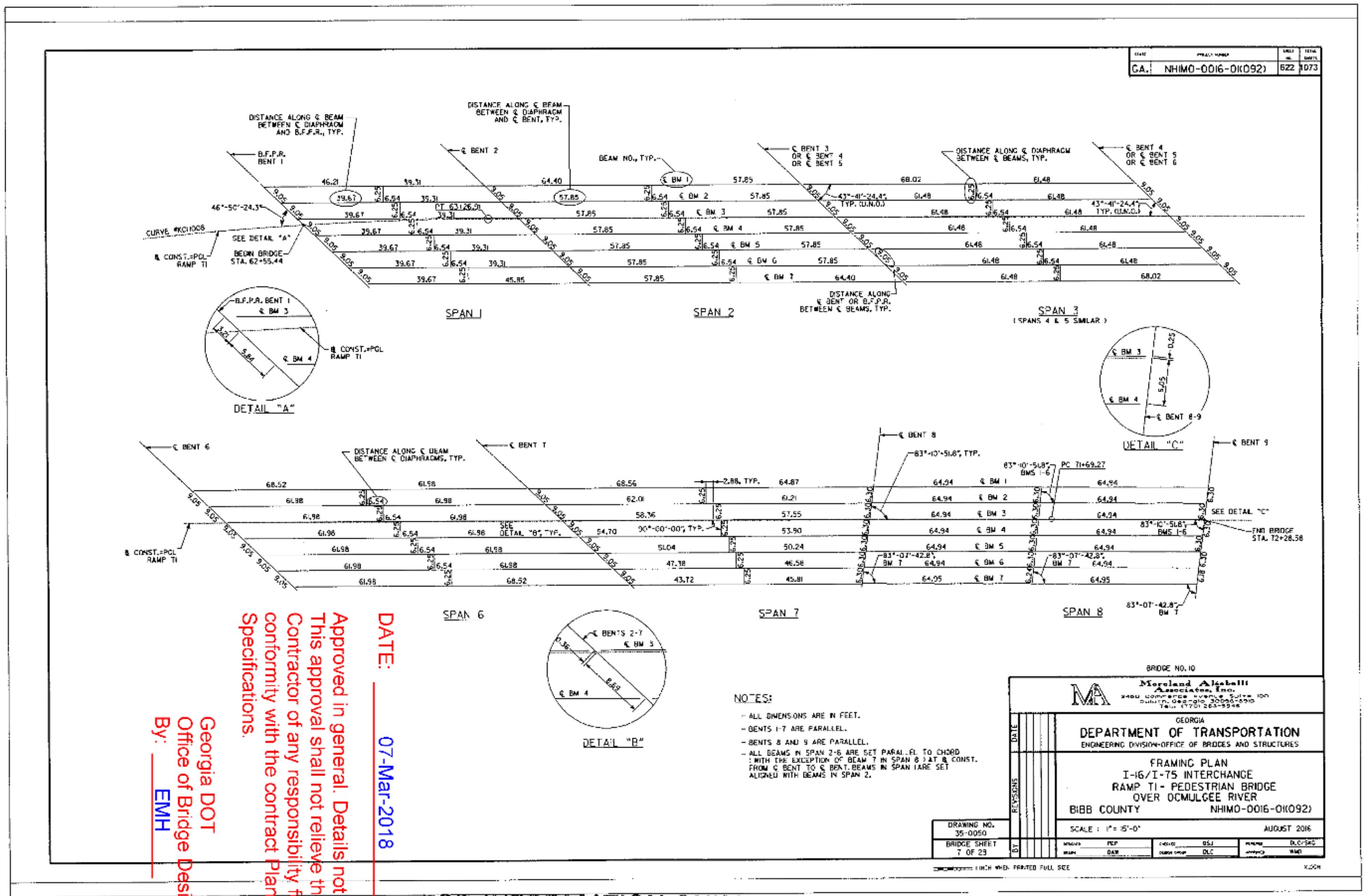
DATE	BY	REVISIONS
11/16/16	BSJ	REMOVED MASS CONCRETE NOTE
1/10/17	BSJ	ADDED/REVISED NOTE, PAY ITEM
3/9/17	LCC	

DRAWING NO. 35-0045
BRIDGE SHEET 2 OF 29

1 INCH WHEN PRINTED FULL SIZE

USE ON CONSTRUCTION

132



DATE: 07-Mar-2018

Approved in general. Details not checked. This approval shall not relieve the Contractor of any responsibility for conformity with the contract Plans and Specifications.

Georgia DOT
Office of Bridge Design
By: EMH

FOR INFORMATION ONLY

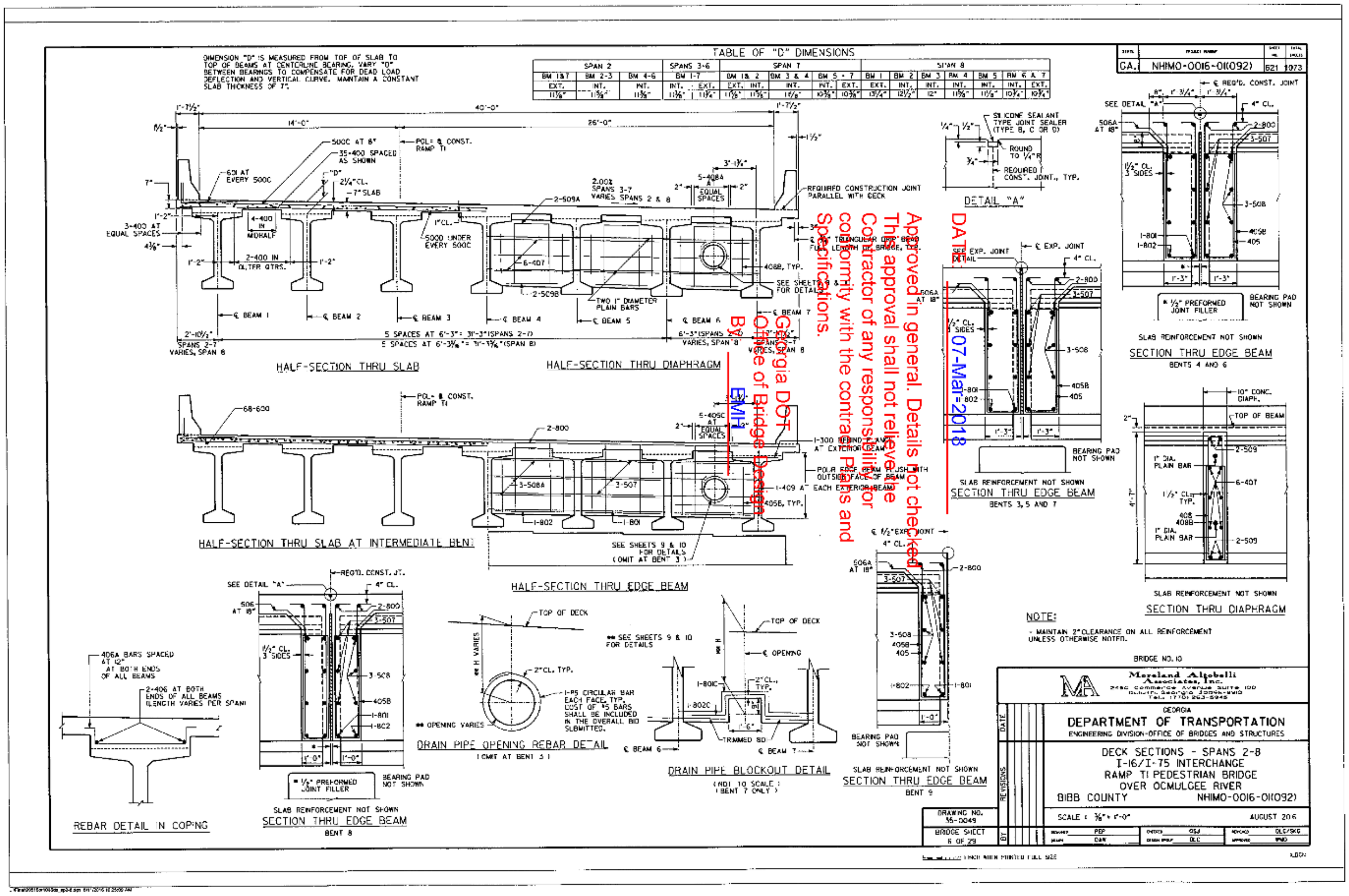


TABLE OF "D" DIMENSIONS
GA. NHIMO-0016-01(092)
HALF-SECTION THRU SLAB
HALF-SECTION THRU DIAPHRAGM
HALF-SECTION THRU SLAB AT INTERMEDIATE BENT
HALF-SECTION THRU EDGE BEAM
DETAIL "A"
SECTION THRU EDGE BEAM
SECTION THRU DIAPHRAGM
REBAR DETAIL IN COPING
DRAIN PIPE OPENING REBAR DETAIL
DRAIN PIPE BLOCKOUT DETAIL
NOTE:
MAINTAIN 2" CLEARANCE ON ALL REINFORCEMENT UNLESS OTHERWISE NOTED.
BRIDGE NO. 10
Moreland Altobelli Associates, Inc.
GEORGIA
DEPARTMENT OF TRANSPORTATION
ENGINEERING DIVISION-OFFICE OF BRIDGES AND STRUCTURES
DECK SECTIONS - SPANS 2-8
I-16/I-75 INTERCHANGE
RAMP T1 PEDESTRIAN BRIDGE
OVER OCMULGEE RIVER
BIBB COUNTY
NHIMO-0016-01(092)
AUGUST 2016
Approved in general. Details not checked.
The approval shall not relieve the
Contractor of any responsibility for
conformity with the contract Plans and
Specifications.
Georgia DOT
Office of Bridge Design
DATE 07-Mar-2018

B4

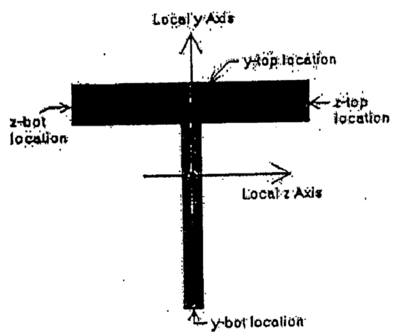
the stress follows the sign of the force.

The shear stresses are calculated as V/A_s, where A_s is the effective shear area. The program obtains A_s by multiplying the total area by the shear stress factor. This factor is calculated automatically for most cross sections, but must be entered for Arbitrary members. Refer to Member Shear Stresses.

The bending stresses are calculated using the familiar equation M * c / I, where "M" is the bending moment, "c" is the distance from the neutral axis to the extreme fiber, and "I" is the moment of inertia. RISA-3D calculates and lists the stress for the section's extreme edge with respect to the positive and negative directions of the local y and/or z axis. A positive stress is compressive and a negative stress is tensile.

Note that two stress values are listed for each bending axis. This is because the stress values for a bending axis will not be the same if the shape isn't symmetric for bending about the axis, as with Tee and Channel shapes. The y-top and y-bot values are the extreme fiber stress for the + or - y-axis locations. The same is true for the z-top and z-bot stresses.

The locations for the calculated stresses are illustrated in this diagram:



DATE: 07-Mar-2018

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So, the y-top location is the extreme fiber of the shape in the positive local y direction, y-bot is the extreme fiber in the negative local y direction, etc. The y-top,bot stresses are calculated using Mz and the z-top,bot stresses are calculated using My.

For enveloped results the maximum and minimum value at each location is listed. The load combination producing the maximum or minimum is also listed, in the "lc" column.

The moving load results are enveloped and will display the Load Combinations with maximum and minimum values shown for each section location, for each active member. The governing load combination and step location is shown for each result value under the "**LC**" column. The first number is the load combination, the second is the step number: (load combination - step number). See Moving Loads to learn more.

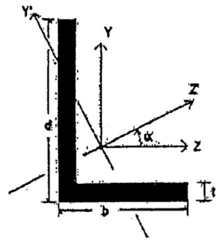
Note

- A special case is bending stress calculations for single angles. The bending stresses for single angles are reported for bending about the principal axes.
- Torsional stress results are listed separately on the Torsion spreadsheet.
- See Spreadsheet Operations to learn how to use **Find**, **Sort**, and other options.
- See Model Display Options - Members to learn how to plot member results.

Single Angle Results

Depending on whether a single angle has been fully restrained against rotation or not it will either behave about its geometric axes or its principal axes. This behavior can be controlled by correctly specifying the unbraced lengths for the angle. In the diagram below the z and y axes are the geometric axes. The z' and y' are the principal axes. The y' axis is considered to be the weak axis for principal behavior, and the z' is considered to be the strong axis.

C2



DATE: 07-Mar-2018

Approved in general. Details not checked. This approval shall not relieve the Contractor of any responsibility for conformity with the contract Plans and Specifications.

Georgia DOT
Office of Bridge Design
By: EMH

The orientation of the shape is defined using the local y and z axes shown in the above diagram, but for principal axis behavior the bending calculations are done with respect to the y' and z' axes shown (the principal axes). The y' axis is the axis of minimum 'I' and the z' axis is the axis of maximum 'I'. RISA calculates the angle "α" and transposes the moments as shown below:

$$Mz' = Mz * \cos(\alpha) + My * \sin(\alpha)$$

$$My' = -Mz * \sin(\alpha) + My * \cos(\alpha)$$

The My' and Mz' moments are the moments shown as My and Mz respectively in the member forces results. Likewise, the y-top and y-bot bending stresses are relative to the extreme fibers along the y' axis (for the Mz' bending moment). The z-top, z-bot stresses are for My' bending at the extreme fiber locations along the z' axis.

Note

- If both LcompTop and LcompBot have been set to zero then the angle will behave about its geometric axes and the member forces and stresses will be displayed relative to the geometric axes. Alternatively, setting the L-torque value to zero will also constrain the single angle to behave about its geometric axes.

Member Torsion Results

Access the **Member Torsion Stresses Spreadsheet** by selecting the **Results** Menu and then selecting **Members** ➔ **Torsion.**

Member Torsion Stresses (By Combination)

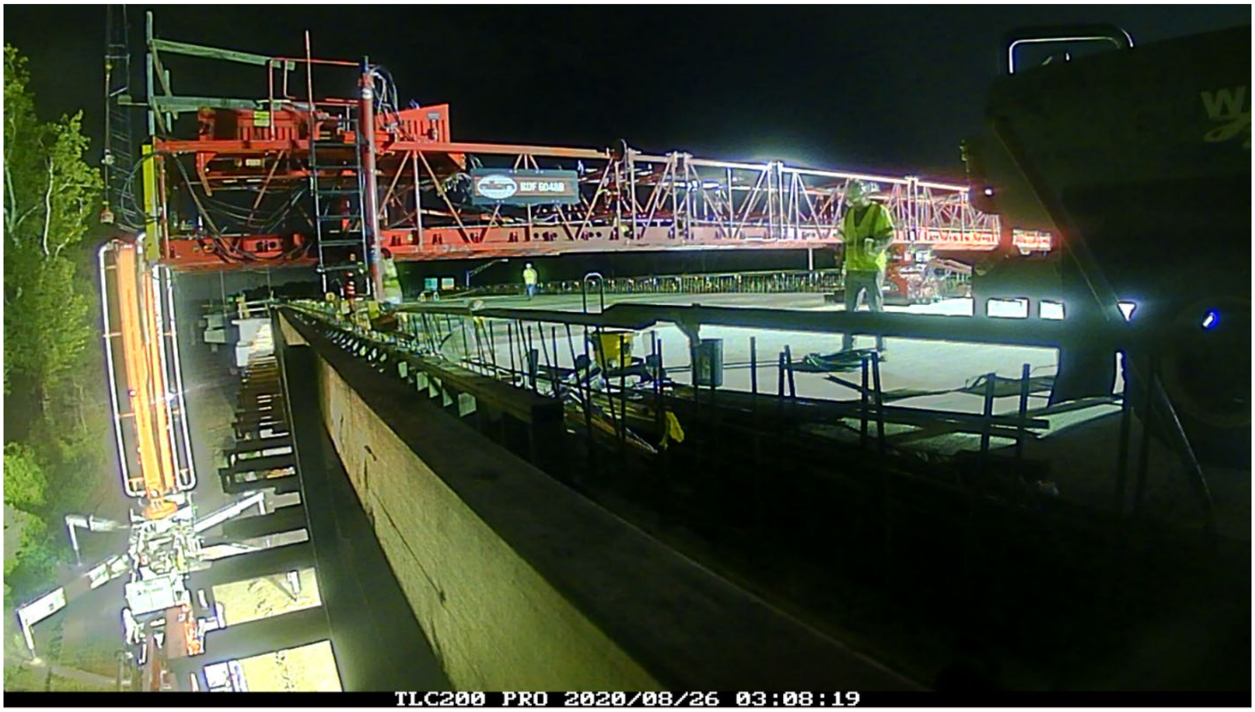
1	M28	1	.381	0	0	.627	13.481	13.481
		2	.19	1.677	0	.17	3.449	3.449
		3	0	0	0	0	0	[illegible]
		4	-.19	-1.677	0	-.17	3.449	3.449
		5	-.381	0	0	-.627	13.481	13.481
1	M29	1	.618	0	0	.656	30.629	30.629
		2	.309	4.507	0	.178	4.87	4.87
		3	0	0	0	0	0	0
		4	-.309	-4.507	0	-.178	4.87	4.87
		5	-.618	0	0	-.656	30.629	30.629
1	M30	1	.361	0	0	.641	17.08	17.08
		2	.185	1.775	0	.171	3.543	3.543
		3	0	0	0	0	0	0
		4	-.185	-1.775	0	-.171	3.543	3.543
		5	-.361	0	0	-.641	17.08	17.08
1	M31	1	0	0	0	0	0	0
		2	0	0	0	0	0	0

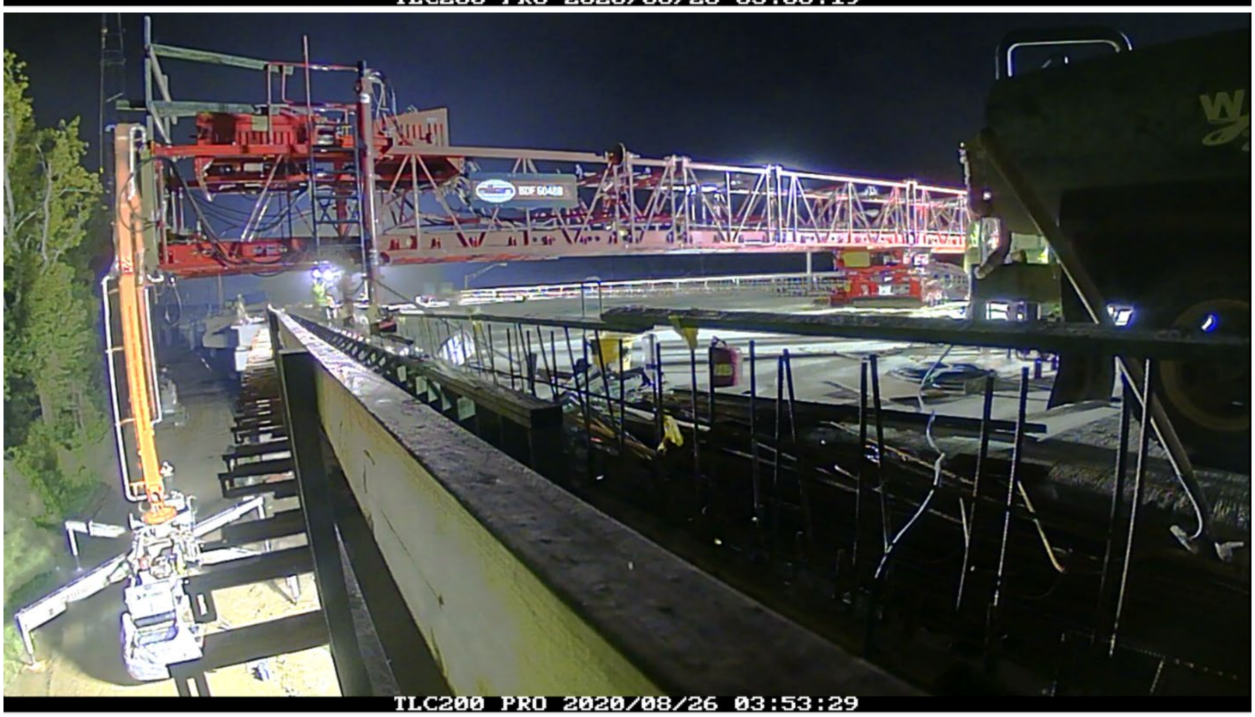
These are the torsional stresses calculated along each member. The number of sections for which torsional stresses are reported is controlled by the **Number of Sections** option on the **Model Settings Dialog.**

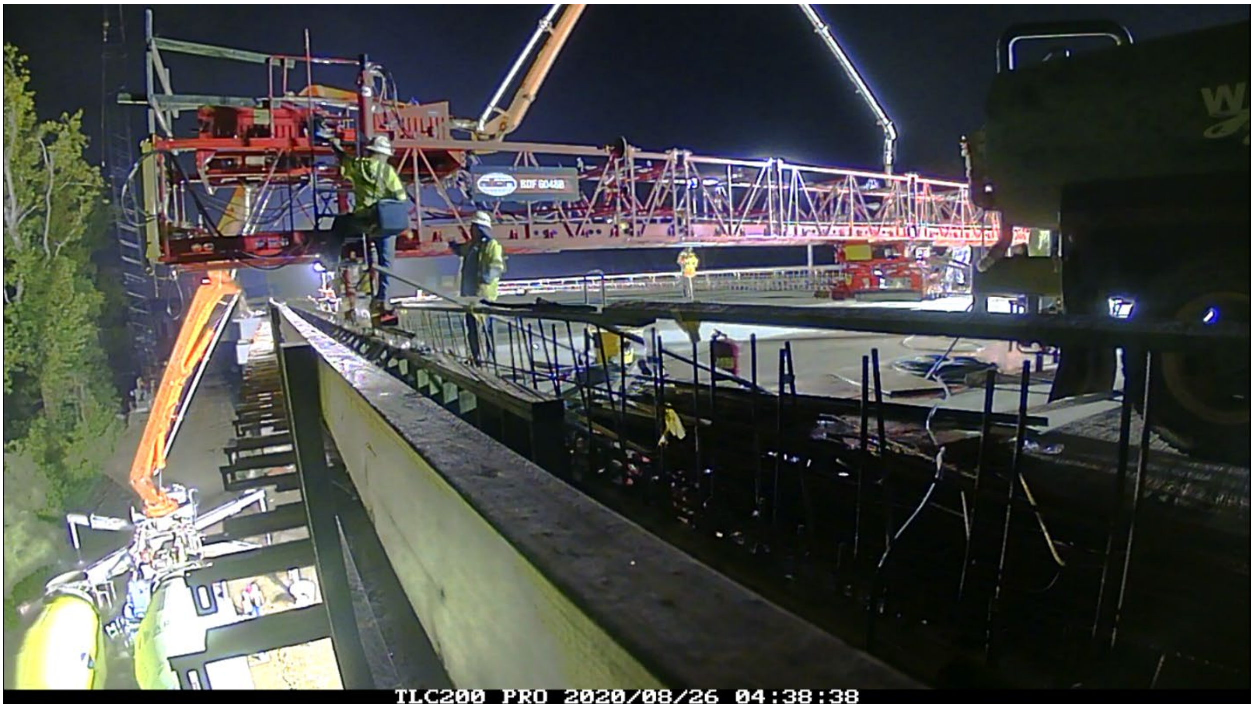
The units for the torsion stresses are shown at the top of each column. RISA-3D calculates pure torsion shear for any shape type; this value is based on the maximum thickness of any part of the cross section. Closed shapes such as tubes and pipes do not warp, nor do solid rectangular or circular shapes. For these shapes there are no warping stresses to report. Warping only occurs in open cross sections where the rectangular pieces that make up the cross section do not all intersect at a single point. For example, a Tee shape could be thought of as two rectangular pieces, the flange and

APPENDIX B: TIME-LAPSE FIGURES

CAMERA 1:

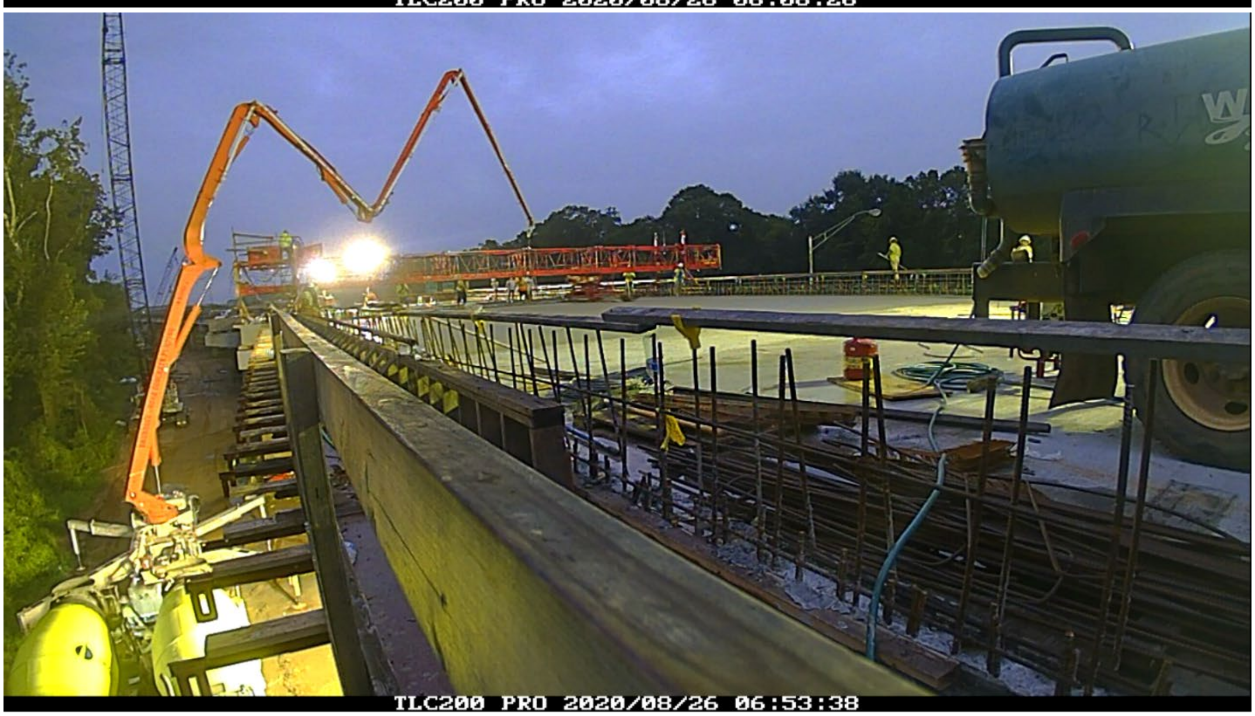





TLC200 PRO 2020/08/26 04:38:38


TLC200 PRO 2020/08/26 05:24:29


TLC200 PRO 2020/08/26 06:08:26


TLC200 PRO 2020/08/26 06:53:38

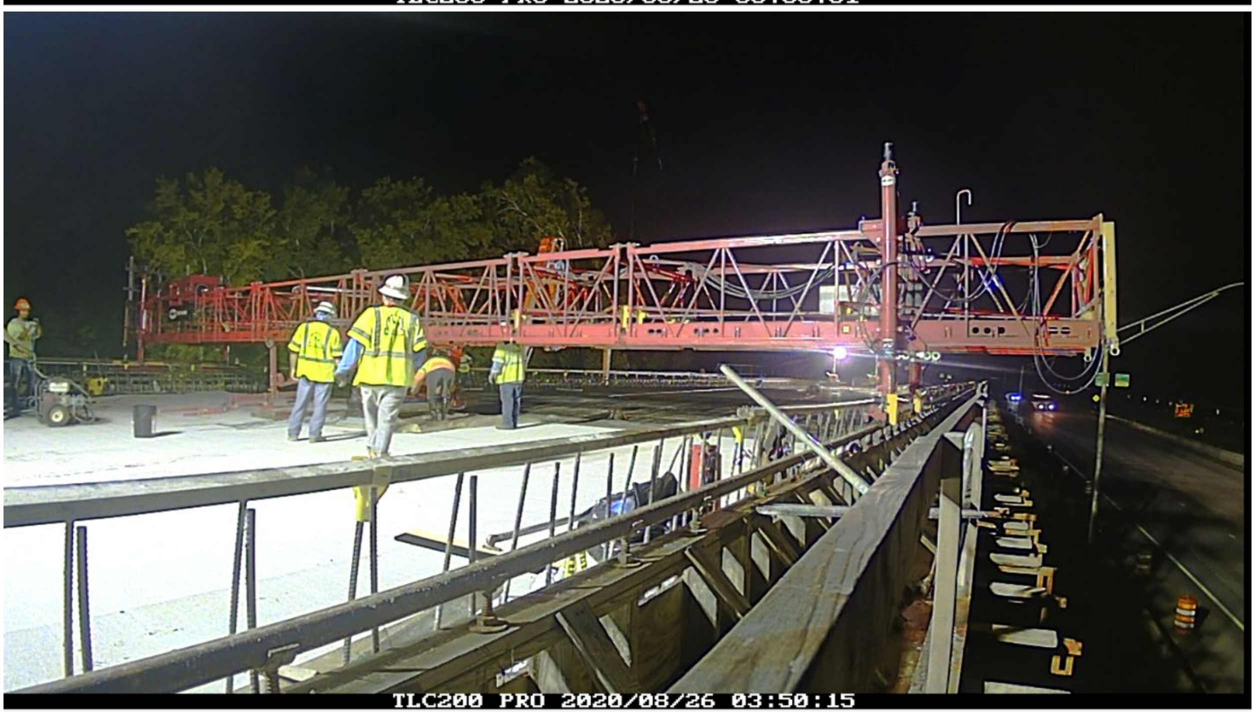

ARGOS
TLC200 PRO 2020/08/26 07:39:32


TLC200 PRO 2020/08/26 08:28:25


TLC200 PRO 2020/08/26 09:17:25


TLC200 PRO 2020/08/26 10:03:28

CAMERA 2:




TLC200 PRO 2020/08/26 04:35:39


TLC200 PRO 2020/08/26 05:20:51


TLC200 PRO 2020/08/26 06:06:03


TLC200 PRO 2020/08/26 06:51:06


TLC200 PRO 2020/08/26 07:36:19


TLC200 PRO 2020/08/26 08:24:54


TLC200 PRO 2020/08/26 09:14:20


TLC200 PRO 2020/08/26 10:02:37

APPENDIX C: MATLAB CODE

```
function [data_out] =
Plot_DAQ_Results_Martlet_3(folder_num)

% Plot Narada and Martlet DAQ Data
% **Caution: this code assumes that Unit # of Martlet is
larger than 100**
%close all;

Gain = 4;
Vex = 3.3;
GF = 2.05;
v = 0.3 ;

if(nargin==1)
    if(strcmp(folder_num,'last'))
        % Plot the last result
        dirc = dir('.\DAQResults\');
        [A,I] = max([dirc(:).datenum]);
        if ~isempty(I)
            run_num = dirc(I).name;
        end
    else
        run_num = folder_num;
    end
else
    % get folder number from user
    run_num = input('Enter Folder Name: ');
end

% if run_num >= 100000
%     error('badInput:unusable:tooLarge','%s','Input is too
large!');
% end

% load parameters from .txt file
path_base = sprintf('.\\DAQResults\\%s\\',run_num);
path = [path_base 'TestName.txt'];
[DAQset] = load_DAQ_settings_Martlet(path);

% Find actual points collected
points1 = DAQset.fs * DAQset.T;
points2 = DAQset.points_per_poll;
if points2 > points1
    points = points1;
elseif mod(points1,points2) ~= 0
```

```
    points = (floor(points1/points2)+1)*points2;
else
    points = points1;
end
num_poll_cycles = ceil(points1/points2);

% Preallocate the memory
data = zeros(DAQset.num_units,
max(max(DAQset.channel_num_list(:,:))),
num_poll_cycles*DAQset.points_per_poll);

% Load the data:
time = 1/DAQset.fs*[1:points]';
for k = 1:DAQset.num_units
    chan = DAQset.channel_num_list(k,:);
    for j = 1:chan
        if (DAQset.chans(k,j,1) == 65 &&
DAQset.chans(k,j,2) == 49)
            filename = [path_base sprintf('U%02d_ADC_A1',
DAQset.unit_list(k,1))];
        elseif(DAQset.chans(k,j,1) == 65 &&
DAQset.chans(k,j,2) == 50)
            filename = [path_base sprintf('U%02d_ADC_A2',
DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 65 &&
DAQset.chans(k,j,2) == 52));
            filename = [path_base sprintf('U%02d_ADC_A4',
DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 65 &&
DAQset.chans(k,j,2) == 53));
            filename = [path_base sprintf('U%02d_ADC_A5',
DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 65 &&
DAQset.chans(k,j,2) == 54));
            filename = [path_base sprintf('U%02d_ADC_A6',
DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 66 &&
DAQset.chans(k,j,2) == 48));
            filename = [path_base sprintf('U%02d_ADC_B0',
DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 66 &&
DAQset.chans(k,j,2) == 49));
            filename = [path_base sprintf('U%02d_ADC_B1',
DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 66 &&
DAQset.chans(k,j,2) == 50));
```

```
            filename = [path_base sprintf('U%02d_ADC_B2',
DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 66 &&
DAQset.chans(k,j,2) == 52));
            filename = [path_base sprintf('U%02d_ADC_B4',
DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 66 &&
DAQset.chans(k,j,2) == 53));
            filename = [path_base sprintf('U%02d_ADC_B5',
DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 66 &&
DAQset.chans(k,j,2) == 54));
            filename = [path_base sprintf('U%02d_ADC_B6',
DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 72 &&
DAQset.chans(k,j,2) == 49));
            filename = [path_base
sprintf('U%02d_EXTADC_CH1', DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 72 &&
DAQset.chans(k,j,2) == 50));
            filename = [path_base
sprintf('U%02d_EXTADC_CH2', DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 72 &&
DAQset.chans(k,j,2) == 51));
            filename = [path_base
sprintf('U%02d_EXTADC_CH3', DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 72 &&
DAQset.chans(k,j,2) == 52));
            filename = [path_base
sprintf('U%02d_EXTADC_CH4', DAQset.unit_list(k,1))];
        end

        tempdata = [];
        ppp = DAQset.points_per_poll;
        for i = 1:num_poll_cycles
            filename_i = [filename '_' num2str(i,'%05d')
'.dat'];
            if DAQset.chans(k,j,1) == 72
                tempdata((i-1)*ppp*2+1:i*ppp*2,1) =
load(filename_i);
            else
                tempdata((i-1)*ppp+1:i*ppp,1) =
load(filename_i);
            end
        end

        %          for i=1:length(tempdata)
```

```
        if DAQset.chans(k,j,1) == 72
            if DAQset.chans(k,j,2) == 52
                for data_i = 1:length(tempdata)/2
                    data_volt(data_i) =
bitshift(tempdata((data_i-1)*2+1),16) + tempdata(data_i*2);
                    data_volt(data_i) =
typecast(uint32(data_volt(data_i)),'int32');
                    data_volt(data_i) =
data_volt(data_i)*2.442/2^31;
                end
            else
                for data_i = 1:length(tempdata)/2
                    data_volt(data_i) =
bitshift(tempdata((data_i-1)*2+1),16) + tempdata(data_i*2);
                    data_volt(data_i) =
typecast(uint32(data_volt(data_i)),'int32');
                    data_volt(data_i) =
data_volt(data_i)*2.442/2^31/1.084/1.759/Gain;
                end
            end

            if DAQset.chans(k,j,1) == 72
                for data_i = 2:length(data_volt)
                    if abs(data_volt(data_i) -
data_volt(data_i-1)) > 0.3
                        data_volt(data_i) =
data_volt(data_i-1);
                    end
                end
            end

            if DAQset.chans(k,j,2) == 52
                data_volt(1) = data_volt(2);
                data_v = -data_volt;
                data_tmp = 5.8145*data_v.^3 +
3.5922*data_v.^2 + 30.245*data_v + 16.111;
            else

                for (i=1:length(data_volt))
                 data_str(1,i) =
data_volt(1,i)*2/Vex/GF/(1+v - data_volt(1,i)/Vex*(1-
v))*10^6;     %mod by N
                end

              %  to delete the spikes if needed.
%                    for i=1:5
```

```
%                       [~,b] = max(data_str);
%                  if b>1
               data_str =(data_str - mean(data_str));
               data_str = data_str - data_str(1,1);
%
            end
        else
                data_volt(data_i) = tempdat;
            for data_i=1:length(tempdata)a(data_i,1) * 3.3
/ 4095;
            end
            data_str = data_volt*15100;
           data_str =(data_str - mean(data_str));
           data_str =(data_str - mean(data_str))-
(data_str(:,1) - mean(data_str));
        end

        if DAQset.chans(k,j,1) == 72

            if DAQset.chans(k,j,2) == 52
                figHand = figure;
                set (figHand, 'Position',[200 200 600
200]);
                plot(time, data_v)
                xlabel('Tims(s)');
                ylabel(['Voltage (V)']);
                display(['Mean value V: '
num2str(mean(data_v))]);
                failn = find(data_v == 0);
                display(['Failure percentage: '
num2str(length(failn)/length(data_v)*100) '%']);
            else
                figHand = figure;
                set (figHand, 'Position',[200 200 600
200]);
                plot(time, data_volt)
                xlabel('Tims(s)');
                ylabel(['Voltage (V)']);
                display(['Mean value V: '
num2str(mean(data_volt))]);
                failn = find(data_volt == 0);
                display(['Failure percentage: '
num2str(length(failn)/length(data_volt)*100) '%']);
            end

            if DAQset.chans(k,j,2) == 52
                figHand = figure;
```

```
                set (figHand, 'Position',[200 200 600
200]);
                plot(time, data_tmp)
                title('thermistor 2')
                xlabel('time(s)');
                ylabel(['temperature (\circ C)']);
                display(['Mean value: '
num2str(mean(data_tmp))]);
                display(['Noise level: '
num2str(std(data_tmp))]);
            else
                figHand = figure;
                set (figHand, 'Position',[200 200 600
200]);
                plot(time, data_str)
                xlabel('Tims(s)');
                ylabel(['Strain (\mu\epsilon)']);
%                 ylim([-100 5])
                legend ('martlet')
                %              ylabel(['Acc (g)']);
                display(['Mean value: '
num2str(mean(data_str))]);
                display(['Noise level: '
num2str(std(data_str))]);
            end

        else
            figHand = figure;
            set (figHand, 'Position',[200 200 600 200]);
            plot(time, data_volt)
            xlabel('Tims(s)');
            ylabel(['Voltage (V)']);
            display(['Mean value V: '
num2str(mean(data_volt))]);
            failn = find(data_volt == 0);
            display(['Failure percentage: '
num2str(length(failn)/length(data_volt)*100) '%']);

            figHand = figure;
            set (figHand, 'Position',[200 200 600 200]);

            plot(time, data_str)
           ylim([-110 5])
            xlabel('Tims(s)');
            ylabel(['Strain (\mu\epsilon)']);
           %             ylabel(['Acc (g)']);
```

```
            display(['Mean value: '
num2str(mean(data_str))]);
            display(['Noise level: '
num2str(std(data_str))]);

        end

    end




end
end


function [DAQset] = load_DAQ_settings_Martlet(path)
% Use this function to automaticlly load the DAQ settings
for a Narada DAQ
% run using the automatically generated .txt file.

fid = fopen([path]);
tline =  fgets(fid);
tline =  fgets(fid);
tline =  fgets(fid);
tline =  fgets(fid);
tline =  fgets(fid);
DAQset.PCTime = sscanf(tline, '\t%s'); %get name
tline = fgets(fid);
tline = fgets(fid);
[DAQset.timestamp] = sscanf(tline, '\t%s'); %get timestamp
tline = fgets(fid);
tline = fgets(fid);
tline = fgets(fid);
tline = fgets(fid);
DAQset.fs = sscanf(tline, '\t\t%d Hz'); % get sample rate
tline = fgets(fid);
tline = fgets(fid);
DAQset.T = sscanf(tline, '\t\t%d seconds'); % get number of
seconds
tline = fgets(fid);
tline = fgets(fid);
DAQset.points_per_poll = sscanf(tline, '\t\t%d samples'); %
get points per polling cycle
tline = fgets(fid);
tline = fgets(fid);
tline = fgets(fid);
```

```
DAQset.num_units = sscanf(tline, '\t- %d %*s'); % get
points per polling cycle
%tline = fgets(fid)
DAQset.unit_list = zeros(DAQset.num_units,1);

tline = fgets(fid);
for k = 1:DAQset.num_units
    temp1 = sscanf(tline,'\t\t- %*s %d'); % flush junk
    DAQset.unit_list(k,1) = temp1;
    num_chan = sscanf(tline,'\t\t- %*s %*d %*s %*s %*s
%d'); % flush junk
    %Assemble Channel Lists:

    for kk = 1 : num_chan

        tline = fgets(fid);
        if tline == -1
            break ;
        elseif tline(3)=='-'
            break ;
        end

        if tline(6) == 'E'
            temp = tline(14:15);
            eval(['chans' int2str(k) '(' int2str(kk) ',:)'
'=' 'temp(1:2)' ';']);    % it is only for Narada.
        else
            temp = tline(10:11);
            eval(['chans' int2str(k) '(' int2str(kk) ',:)'
'=' 'temp(1:2)' ';']);    % it is only for Narada.
        end
    end
    tline = fgets(fid);
end
fclose(fid);

DAQset.channel_num_list = zeros(DAQset.num_units,1);
for k = 1:DAQset.num_units
    temp = eval(['size(chans' int2str(k) ');']);
    DAQset.channel_num_list(k,1) = temp(1);
end
DAQset.chans =
zeros(DAQset.num_units,max(DAQset.channel_num_list),2);
for k = 1:DAQset.num_units
    for j = 1:DAQset.channel_num_list(k,1)
        eval(['DAQset.chans(k,j,:) = chans' int2str(k)
'(j,:);']);
```

```
    end
end

function data = lvm_import(filename,verbose)
%LVM_IMPORT Imports data from a LabView LVM file
% DATA = LVM_IMPORT(FILENAME,VERBOSE) returns the data from
a LVM (.lvm)
%  ASCII text file created by LabView.
%
% FILENAME    The name of the .lvm file, with or without
".lvm" extension
%
% VERBOSE     How many messages to display. Default is 1
(few messages),
%              0 = silent, 2 = display file information and
all messages
%
% DATA        The data found in the LVM file. DATA is a
structure with
%              fields corresponding to the Segments in the
file (see below)
%              and LVM file header information.
%
%
% This function imports data from a text-formatted LabView
Measurement File
%  (LVM, extension ".lvm") into MATLAB. A LVM file can have
multiple
%  Segments, so that multiple measurements can be combined
in a single
%  file. The output variable DATA is a structure with
fields named
%  'Segment1', 'Segment2', etc. Each Segment field is a
structure with
%  details about the data in the Segment and the actual
data in the field
%  named 'data'. The column labels and units are stored as
cell arrays that
%  correspond to the columns in the array of data.
% The size of the data array depends on the type of x-axis
data that is
%  stored in the LVM file and the number of channels
(num_channels).
%  There are three cases:
%  1) No x-data is included in the file ('No')
%   The data array will have num_channels columns (one
column per channel
```

```
%   of data).
%  2) One column of x-data is included in the file ('One')
%   The first column of the data array will be the x-
values, and the data
%   array will have num_channels+1 columns.
%  3) Each channel has its own x-data ('Multi')
%   Each channel has two columns, one for x-values, and one
for data. The
%   data array will have num_channels*2 columns, with the
x-values and
%   corresponding data in alternating columns. For example,
in a Segment
%   with 4 channels, columns 1,3,5,7 will be the x-values
for the data in
%   columns 2,4,6,8.
%
% Note: because MATLAB only works with a "." decimal
separator, importing
%  large LVM files that use a "," (or other character) will
be noticeably
%  slower. Use a "." decimal separator to avoid this issue.
%
% The LVM file specification is available at:
%   http://zone.ni.com/devzone/cda/tut/p/id/4139
%
%
% Example:
%
%  Use the following command to read in the data from a
file containing two
%   Segments:
%
% >> d=lvm_import('testfile.lvm');
%
% Importing testfile.lvm:
%
% Import complete. 2 Segments found.
%
% >> d
% d =
%       X_Columns: 'One'
%            user: 'hopcroft'
%     Description: 'Pressure, Flowrate, Heat, Power, Analog
Voltage, Pump on, Temp'
%            date: '2008/03/26'
%            time: '12:18:02.156616'
%           clock: [2008 3 26 12 18 2.156616]
```

```
%        Segment1: [1x1 struct]
%        Segment2: [1x1 struct]
%
% >> d.Segment1
% ans =
%             Notes: 'Some notes regarding this data set'
%      num_channels: 8
%           y_units: {8x1 cell}
%           x_units: {8x1 cell}
%                X0: [8x1 double]
%           Delta_X: [8x1 double]
%     column_labels: {9x1 cell}
%              data: [211x9 double]
%           Comment: 'This data rulz'
%
% >> d.Segment1.column_labels{2}
% ans =
% Thermocouple1
%
% >> plot(d.Segment1.data(:,1),d.Segment1.data(:,2));
% >> xlabel(d.Segment1.column_labels{1});
% >> ylabel(d.Segment1.column_labels{2});
%
%
%
% M.A. Hopcroft
%      < mhopeng at gmail.com >
%

% MH Sep2017
% v3.12 fix bug for importing data-only files
%       (thanks to Enrique Alvarez for bug reporting)
% MH Mar2017
% v3.1  use cellfun to vectorize processing of comma-
delimited data
%       (thanks to Victor for suggestion)
% v3.0  use correct test for 'tab'
% MH Aug2016
% v3.0  (BETA) fixes for files that use comma as delimiter
%       improved robustness for files with missing columns
% MH Sep2013
% v2.2  fixes for case of comma separator in multi-segment
files
%       use cell2mat for performance improvement
%       (thanks to <die-kenny@t-online.de> for bug report
and testing)
% MH May2012
```

```
% v2.1  handle "no separator" bug
%       (thanks to <adnan.cheema@gmail.com> for bug report
and testing)
%       code & comments cleanup
%       remove extraneous column labels (X_Value for "No X"
files; Comment)
%       clean up verbose output
%       change some field names to NI names
("Delta_X","X_Columns","Date")
% MH Mar2012
% v2.0  fix "string bug" related to comma-separated
decimals
%       handle multiple Special Headers correctly
%       fix help comments
%       increment version number to match LabView LVM
writer
% MH Sep2011
% v1.3  handles LVM Writer version 2.0 (files with decimal
separator)
%       Note: if you want to work with older files with a
non-"." decimal
%       separator character, change the value of
"data.Decimal_Separator"
% MH Sep2010
% v1.2  bugfixes for "Special" header in LVM files.
%        (Thanks to <bobbyjoe23928@gmail.com> for
suggestions)
% MH Apr2010
% v1.1  use case-insensitive comparisons to maintain
compatibility with
%        NI LVM Writer version 1.00
%
% MH MAY2009
% v1.02 Add filename input
% MH SEP2008
% v1.01 Fix comments, add Cells
% v1.00 Handle all three possibilities for X-columns
(No,One,Multi)
%       Handle LVM files with no header
% MH AUG2008
% v0.92 extracts Comment for each Segment
% MH APR2008
% v0.9  initial version
%

%#ok<*ASGLU>
```

```
% message level
if nargin < 2, verbose = 1; end % use 1 for release and 2
for BETA
if verbose >= 1, fprintf(1,'\nlvm_import v3.1\n'); end

% ask for filename if not provided already
if nargin < 1
    filename=input(' Enter the name of the .lvm file:
','s');
    fprintf(1,'\n');
end


%% Open the data file
% open and verify the file
fid=fopen(filename);
if fid ~= -1, % then file exists
    fclose(fid);
else
    filename=strcat(filename,'.lvm');
    fid=fopen(filename);
    if fid ~= -1, % then file exists
        fclose(fid);
    else
        error(['File not found in current directory! (' pwd
')']);
    end
end

% open the validated file
fid=fopen(filename);

if verbose >= 1, fprintf(1,' Importing "%s"\n\n',filename);
end

% is it really a LVM file?
linein=fgetl(fid);
if verbose >= 2, fprintf(1,'%s\n',linein); end
% Some LabView routines create an LVM file with no header;
just a text file
%  with columns of numbers. We can try to import this kind
of data.
if isempty(strfind(linein,'LabVIEW'))
    try
        data.Segment1.data = dlmread(filename);
        if verbose >= 1, fprintf(1,'This file appears to be
an LVM file with no header.\n'); end
```

```
        if verbose >= 1, fprintf(1,'Data was copied, but no
other information is available.\n'); end
        return
    catch fileEx
        error('This does not appear to be a text-format LVM
file (no recognizeable header or data).');
    end
end


%% Process file header
% The file header contains several fields with useful
information

% default values
data.Decimal_Separator = '.';
text_delimiter={',',' ','\t'};
data.X_Columns='One';

% File header contains date, time, etc.
% Also the file delimiter and decimal separator (LVM v2.0)
if verbose >= 2, fprintf(1,' File Header Contents:\n\n');
end
while 1

    % get a line from the file
    linein=fgetl(fid);
    % handle spurious carriage returns
    if isempty(linein), linein=fgetl(fid); end
    if verbose >= 3, fprintf(1,'%s\n',linein); end
    % what is the tag for this line?
    t_in =
textscan(linein,'%s','Delimiter',text_delimiter);
    if isempty(t_in{1}{1})
        tag='notag';
    else
        tag = t_in{1}{1};
    end
    % exit when we reach the end of the header
    if strfind(tag,'***End_of_Header***')
        if verbose >= 2, fprintf(1,'\n'); end
        break
    end

    % get the value corresponding to the tag
%     if ~strcmp(tag,'notag')
```

```
%          v_in = textscan(linein,'%*s
%s','delimiter','\t','whitespace','','MultipleDelimsAsOne',
1);
        if size(t_in{1},1)>1 % only process a tag if it has
a value
%              val = v_in{1}{1};
            val = t_in{1}{2};

            switch tag
                case 'Date'
                    data.Date = val;
                case 'Time'
                    data.Time = val;
                case 'Operator'
                    data.user = val;
                case 'Description'
                    data.Description = val;
                case 'Project'
                    data.Project = val;
                case 'Separator'
                    % v3 separator sanity check
                    if strcmpi(val,'Tab')
                        text_delimiter='\t';
                        if strfind(linein,',')
                            fprintf(1,'ERROR: File header
reports "Tab" but uses ",". Check the file and correct if
necessary.\n');
                            return
                        end
                    elseif strcmpi(val,'Comma') ||
strcmpi(val,',')
                        text_delimiter=',';
                        if strfind(linein,sprintf('\t'))
                            fprintf(1,'ERROR: File header
reports "Comma" but uses "tab". Check the file and correct
if necessary.\n');
                            return
                        end
                    end

                case 'X_Columns'
                    data.X_Columns = val;
                case 'Decimal_Separator'
                    data.Decimal_Separator = val;
            end
            if verbose >= 2, fprintf(1,'%s: %s\n',tag,val);
end
```

```
        end
%      end

end

% create matlab-formatted date vector
if isfield(data,'time') && isfield(data,'date')
    dt = textscan(data.Date,'%d','Delimiter','/');
    tm = textscan(data.Time,'%d','Delimiter',':');
    if length(tm{1})==3
        data.clock=[dt{1}(1) dt{1}(2) dt{1}(3) tm{1}(1)
tm{1}(2) tm{1}(3)];
    elseif length(tm{1})==2
        data.clock=[dt{1}(1) dt{1}(2) dt{1}(3) tm{1}(1)
tm{1}(2) 0];
    else
        data.clock=[dt{1}(1) dt{1}(2) dt{1}(3) 0 0 0];
    end
end

if verbose >= 3, fprintf(1,' Text delimiter is
"%s":\n\n',text_delimiter); end


%% Process segments
% process data segments in a loop until finished
segnum = 1;
val=[]; tag=[]; %#ok<NASGU>
while 1
    %segnum = segnum +1;
    fieldnm = ['Segment' num2str(segnum)];

    %% - Segment header
    if verbose >= 1, fprintf(1,' Segment %d:\n\n',segnum);
end
    % loop to read segment header
    while 1
        % get a line from the file
        linein=fgetl(fid);
        % handle spurious carriage returns/blank lines/end
of file
        while isempty(linein), linein=fgetl(fid); end
        if feof(fid), break; end
        if verbose >= 3, fprintf(1,'%s\n',linein); end

        % Ignore "special segments"
```

```
        % "special segments" can hold other types of data.
The type tag is
        % the first line after the Start tag. As of version
2.0,
        % LabView defines three types:
        %  Binary_Data
        %  Packet_Notes
        %  Wfm_Sclr_Meas
        % In theory, users can define their own types as
well. LVM_IMPORT
        %  ignores any "special segments" it finds.
        % If special segments are handled in future
versions, recommend
        %  moving the handler outside the segment read
loop.
        if strfind(linein,'***Start_Special***')
            special_seg = 1;
            while special_seg

                while 1 % process lines until we find the
end of the special segment
                    % get a line from the file
                    linein=fgetl(fid);
                    % handle spurious carriage returns
                    if isempty(linein), linein=fgetl(fid);
end
                    % test for end of file
                    if linein==-1, break; end
                    if verbose >= 2,
fprintf(1,'%s\n',linein); end
                    if strfind(linein,'***End_Special***')
                        if verbose >= 2, fprintf(1,'\n');
end
                        break
                    end
                end

                % get the next line and proceed with file
                %  (there may be additional Special
Segments)
                linein=fgetl(fid);
                % handle spurious carriage returns/blank
lines/end of file
                while isempty(linein), linein=fgetl(fid);
end
                if feof(fid), break; end
```

```
                if
isempty(strfind(linein,'***Start_Special***'))
                    special_seg = 0;
                    if verbose >= 1, fprintf(1,' [Special
Segment ignored]\n\n'); end
                end
            end
        end % end special segment handler


        % what is the tag for this line?
        t_in =
textscan(linein,'%s','Delimiter',text_delimiter);
        if isempty(t_in{1}{1})
            tag='notag';
        else
            tag = t_in{1}{1};
            %disp(t_in{1})
        end
        if verbose >= 3, fprintf(1,'%s\n',linein); end
        % exit when we reach the end of the header
        if strfind(tag,'***End_of_Header***')
            if verbose >= 3, fprintf(1,'\n'); end
            break
        end

        % get the value corresponding to the tag
        % v3 assignments use dynamic field names
        if size(t_in{1},1)>1 % only process a tag if it has
a value
            switch tag
                case 'Notes'
    %                   %d_in = textscan(linein,'%*s
%s','delimiter','\t','whitespace','');
    %                   d_in = linein;
                    data.(fieldnm).Notes = t_in{1}{2:end};
                case 'Test_Name'
    %                   %d_in = textscan(linein,'%*s
%s','delimiter','\t','whitespace','');
    %                   d_in = linein;
                    data.(fieldnm).Test_Name =
t_in{1}{2:end};  %d_in{1}{1};
                case 'Channels'
    %                   numchan =
textscan(linein,sprintf('%%*s%s%%d',text_delimiter),1)
    %                   data.(fieldnm).num_channels =
numchan{1};
```

```
                    data.(fieldnm).num_channels =
str2num(t_in{1}{2});
                case 'Samples'
    %                 numsamp =
textscan(linein,'%s','delimiter',text_delimiter);
    %                 numsamp1 = numsamp{1};
                    numsamp1 = t_in{1}(2:end);
    %                 numsamp1(1)=[]; % remove tag
"Samples"
                    num_samples=[];
                    for k=1:length(numsamp1)
                        num_samples = [num_samples
sscanf(numsamp1{k},'%f')]; %#ok<AGROW>
                    end
                    %numsamp2=str2num(cell2mat(numsamp1));
%#ok<ST2NM>
                    data.(fieldnm).num_samples =
num_samples;
                case 'Y_Unit_Label'
    %                 Y_units =
textscan(linein,'%s','delimiter',text_delimiter);
    %                 data.(fieldnm).y_units=Y_units{1}';
                    data.(fieldnm).y_units=t_in{1}';
                    data.(fieldnm).y_units(1)=[]; % remove
tag
                case 'Y_Dimension'
    %                 Y_Dim =
textscan(linein,'%s','delimiter',text_delimiter);
    %                 data.(fieldnm).y_type=Y_Dim{1}';
                    data.(fieldnm).y_type=t_in{1}';
                    data.(fieldnm).y_type(1)=[]; % remove
tag
                case 'X_Unit_Label'
    %                 X_units =
textscan(linein,'%s','delimiter',text_delimiter);
    %                 data.(fieldnm).x_units=X_units{1}';
                    data.(fieldnm).x_units=t_in{1}';
                    data.(fieldnm).x_units(1)=[];
                case 'X_Dimension'
    %                 X_Dim =
textscan(linein,'%s','delimiter',text_delimiter);
    %                 data.(fieldnm).x_type=X_Dim{1}';
                    data.(fieldnm).x_type=t_in{1}';
                    data.(fieldnm).x_type(1)=[]; % remove
tag
                case 'X0'
                    %[Xnought, val]=strtok(linein);
```

```
                    val=t_in{1}(2:end);
                    if ~strcmp(data.Decimal_Separator,'.')
                        val =
strrep(val,data.Decimal_Separator,'.');
                    end
                    X0=[];
                    for k=1:length(val)
                        X0 = [X0 sscanf(val{k},'%e')];
%#ok<AGROW>
                    end
                    data.(fieldnm).X0 = X0;
                    %data.(fieldnm).X0 =
textscan(val,'%e');
                case 'Delta_X' %,
                    %[Delta_X, val]=strtok(linein);
                    val=t_in{1}(2:end);
                    if ~strcmp(data.Decimal_Separator,'.')
                        val =
strrep(val,data.Decimal_Separator,'.');
                    end
                    Delta_X=[];
                    for k=1:length(val)
                        Delta_X = [Delta_X
sscanf(val{k},'%e')]; %#ok<AGROW>
                    end
                    data.(fieldnm).Delta_X = Delta_X;
            end
        end

    end % end reading segment header loop
    % Done reading segment header

    % after each segment header is the row of column labels
    linein=fgetl(fid);
    Y_labels =
textscan(linein,'%s','delimiter',text_delimiter);
    data.(fieldnm).column_labels=Y_labels{1}';
    % The X-column always exists, even if it is empty.
Remove if not used.
    if strcmpi(data.X_Columns,'No')
        data.(fieldnm).column_labels(1)=[];
    end
    % remove empty entries and "Comment" label
    if any(strcmpi(data.(fieldnm).column_labels,'Comment'))

data.(fieldnm).column_labels=data.(fieldnm).column_labels(1
:find(strcmpi(data.(fieldnm).column_labels,'Comment'))-1);
```

```
    end
    % display column labels
    if verbose >= 1
        fprintf(1,' %d Data Columns:\n |
',length(data.(fieldnm).column_labels));
        for i=1:length(data.(fieldnm).column_labels)
            fprintf(1,'%s |
',data.(fieldnm).column_labels{i});
        end
        fprintf(1,'\n\n');
    end



    %% - Segment Data
    % Create a format string for textscan depending on the
number/type of
    %  channels. If there are additional segments, texscan
will quit when
    %  it comes to a text line which does not fit the
format, and the loop
    %  will repeat.
    if verbose >= 1, fprintf(1,' Importing data from
Segment %d...',segnum); end

    % How many data columns do we have? (including X data)
    switch data.X_Columns
        case 'No'
            % an empty X column exists in the file
            numdatacols = data.(fieldnm).num_channels+1;
            xColPlural='no X-Columns';
        case 'One'
            numdatacols = data.(fieldnm).num_channels+1;
            xColPlural='one X-Column';
        case 'Multi'
            numdatacols = data.(fieldnm).num_channels*2;
            xColPlural='multiple X-Columns';
    end

    % handle case of not using periods (aka "dot" or ".")
for decimal point separators
    %  (LVM version 2.0+)
    if ~strcmp(data.Decimal_Separator,'.')
        if verbose >= 2, fprintf(1,'\n  (using decimal
separator "%s")\n',data.Decimal_Separator); end
```

```
        % create a format string for reading data as
numbers
        fs = '%s'; for i=2:numdatacols, fs = [fs ' %s'];
end                  %#ok<AGROW>
        % add one more column for the comment field
        fs = [fs ' %s'];
%#ok<AGROW>
        % v3.1 - use cellfun to process data
        % Read columns as strings
        rawdata =
textscan(fid,fs,'delimiter',text_delimiter);
        % Convert ',' decimal separator to '.' decimal
separator
        rawdata = cellfun(@(x)
strrep(x,data.Decimal_Separator,'.'), rawdata,
'UniformOutput', false);
        % save first row comment as The Comment for this
segment
        data.(fieldnm).Comment =
rawdata{size(rawdata,2)}{1};
        % Transform strings back to numbers
        rawdata = cellfun(@(x) str2double(x), rawdata,
'UniformOutput', false);

    % else is the typical case, with a '.' decimal
separator
    else
        % create a format string for reading data as
numbers
        fs = '%f'; for i=2:numdatacols, fs = [fs ' %f'];
end                      %#ok<AGROW>
        % add one more column for the comment field
        fs = [fs ' %s'];
%#ok<AGROW>
        % read the data from file
        rawdata =
textscan(fid,fs,'delimiter',text_delimiter);
        % save first row comment as The Comment for this
segment
        data.(fieldnm).Comment =
rawdata{size(rawdata,2)}{1};
    end

    % v2.2 use cell2mat here instead of a loop for better
performance
    % consolidate data into a simple array, ignore comments
    data.(fieldnm).data=cell2mat(rawdata(:,1:numdatacols));
```

```
    % If we have a "No X data" file, remove the first
column (it is empty/NaN)
    if strcmpi(data.X_Columns,'No')
        data.(fieldnm).data=data.(fieldnm).data(:,2:end);
    end

    if verbose >= 1, fprintf(1,' complete (%g data points
(rows)).\n\n',length(data.(fieldnm).data)); end

    % test for end of file
    if feof(fid)
        if verbose >= 2, fprintf(1,' [End of File]\n\n');
end
        break;
    else
        segnum = segnum+1;
    end


end % end process segment


if verbose >= 1
    if segnum > 1, segplural='Segments';
    else segplural='Segment'; end
    fprintf(1,'\n Import complete. File has %s and %d Data
%s.\n\n',xColPlural,segnum,segplural);
end


% close the file
fclose(fid);
return

%% input
Gain = 2;
Vex = 3.3;
GF = 2.05;
v = 0.3 ;
count = 0;
n_channels  = 8 ;
run_num ='LAPTOP-288A8P0F_20190730_111223_PCTime';%
'LAPTOP-288A8P0F_20190730_123107_PCTime'; %'LAPTOP-
288A8P0F_20190730_111223_PCTime'; % martlet file name
ni_filename = '20190730_test_9'; % '20190730_test_11' ;%
%ni file name
```

```
%run_num = 'LAPTOP-288A8P0F_20190808_120341_PCTime';

% run_num = 'LAPTOP-288A8P0F_20190730_123107_PCTime'; %
martlet file name
% ni_filename = '20190730_test_11'; %ni file name


dirc = dir('.\DAQResults\');
path_base = sprintf('.\\DAQResults\\%s\\',run_num);
path = [path_base 'TestName.txt'];


[DAQset] = load_DAQ_settings_Martlet(path);

% Find actual points collected
points1 = DAQset.fs * DAQset.T;
points2 = DAQset.points_per_poll;
if points2 > points1
    points = points1;
elseif mod(points1,points2) ~= 0
    points = (floor(points1/points2)+1)*points2;
else
    points = points1;
end
num_poll_cycles = ceil(points1/points2);

% Preallocate the memory
data = zeros(DAQset.num_units,
max(max(DAQset.channel_num_list(:,:))),
num_poll_cycles*DAQset.points_per_poll);
% Load the data:
time = 1/DAQset.fs*[1:points]';
data_str = zeros(n_channels , length (time));
for k = 1:DAQset.num_units
    chan = DAQset.channel_num_list(k,:);
    for j = 1:chan
        count = count + 1;
        if((DAQset.chans(k,j,1) == 72 &&
DAQset.chans(k,j,2) == 49))
            filename = [path_base
sprintf('U%02d_EXTADC_CH1', DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 72 &&
DAQset.chans(k,j,2) == 50))
            filename = [path_base
sprintf('U%02d_EXTADC_CH2', DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 72 &&
DAQset.chans(k,j,2) == 51))
```

```
            filename = [path_base
sprintf('U%02d_EXTADC_CH3', DAQset.unit_list(k,1))];
        elseif((DAQset.chans(k,j,1) == 72 &&
DAQset.chans(k,j,2) == 52))
            filename = [path_base
sprintf('U%02d_EXTADC_CH4', DAQset.unit_list(k,1))];
        end

        tempdata = [];
        ppp = DAQset.points_per_poll;
        for i = 1:num_poll_cycles
            filename_i = [filename '_' num2str(i,'%05d')
'.dat'];
            if DAQset.chans(k,j,1) == 72
                tempdata((i-1)*ppp*2+1:i*ppp*2,1) =
load(filename_i);
            else
                tempdata((i-1)*ppp+1:i*ppp,1) =
load(filename_i);
            end
        end


        if DAQset.chans(k,j,1) == 72
            if DAQset.chans(k,j,2) == 52
                for data_i = 1:length(tempdata)/2

                    data_volt(data_i) =
bitshift(tempdata((data_i-1)*2+1),16) + tempdata(data_i*2);
                    data_volt(data_i) =
typecast(uint32(data_volt(data_i)),'int32');
                    data_volt(data_i) =
data_volt(data_i)*2.442/2^31;
                end
            else
                for data_i = 1:length(tempdata)/2
                    data_volt(data_i) =
bitshift(tempdata((data_i-1)*2+1),16) + tempdata(data_i*2);
                    data_volt(data_i) =
typecast(uint32(data_volt(data_i)),'int32');
                    data_volt(data_i) =
data_volt(data_i)*2.442/2^31/1.084/1.759/Gain;
                end
            end

            if DAQset.chans(k,j,1) == 72
                for data_i = 2:length(data_volt)
```

```
                    if abs(data_volt(data_i) -
data_volt(data_i-1)) > 0.3
                        data_volt(data_i) =
data_volt(data_i-1);
                    end
                end
            end

            if DAQset.chans(k,j,2) == 52
                data_volt(1) = data_volt(2);
                data_v = -data_volt;
                data_tmp = 5.8145*data_v.^3 +
3.5922*data_v.^2 + 30.245*data_v + 16.111;
            else
                for i=1:length(data_volt)
                    data_str(count,i) =
data_volt(1,i)*2/Vex/GF/(1+v - data_volt(1,i)/Vex*(1-
v))*10^6;    %mod by N

                    % data_str(count,i) = data_volt(1,
i)*2/3.3/2.04/0.697*1000000;


                end




                data_str = data_str - data_str(:,1);

            end
        end
    end
end

data_str = data_str([1 2 4 5 7 8 10 11 ],:);


for i=1:n_channels
    for e=1:4
        [~,b] = max(data_str(i,:));
        if b>1
            data_str(i,b) =  data_str(i,b-1);
        end
        [~,b] = min(data_str(i,:));
        if b>1
            data_str(i,b) =  data_str(i,b-1);
```

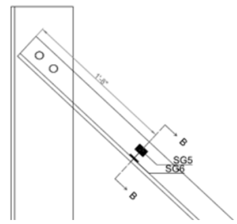
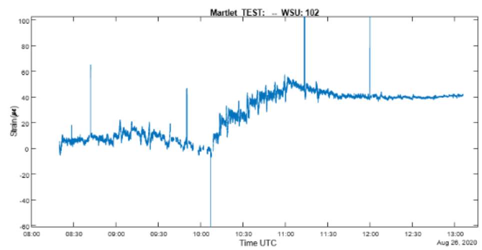
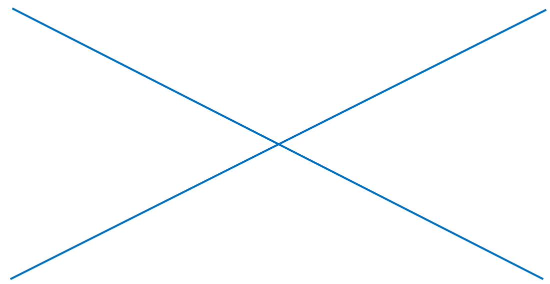
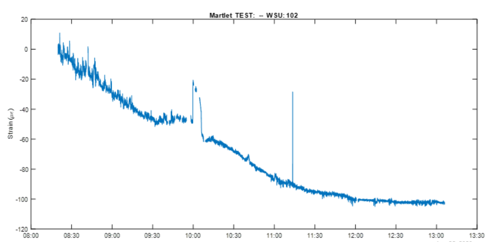
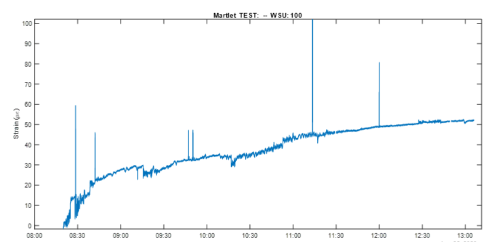
```
        end
    end
end

%% NI
n_qbsq = 12;
n_fbsg = 4;
cd DataAcquisitionNI
%DAQ = lvm_import([num2str(testdate),'_test_',
num2str(testn)  ,'.lvm'], 0);
DAQ = lvm_import(ni_filename, 0);
cd ..

t = DAQ.Segment1.data(:,1);
QBSG(:,1:n_qbsq) = DAQ.Segment1.data(:,2:2+n_qbsq-1)*10^6;
FBSG(:,1:n_fbsg) = -DAQ.Segment1.data(:,14:14+n_fbsg-
1)*10^6;
lvdt1 = DAQ.Segment1.data(:,19);
lvdt2 = DAQ.Segment1.data(:,18);
sp1a = DAQ.Segment1.data(:,20);
LC = -DAQ.Segment1.data(:,21);

n_cycles = time(end)/60;
t_loss = 3; % 2 sconds lost
newtime = [time', time(end)+1:time(end)+t_loss*n_cycles]';
for i=1:n_cycles

    if t_loss == 2
        if i<=1
            newdata_str(:,1:60*i+(i-1)*t_loss) =
data_str(:, 1:60*i);
            newdata_str(:,60*i+(i-1)*t_loss  + 1) =
data_str(:, 60*i);
            newdata_str(:,60*i+(i-1)*t_loss  + 2) =
data_str(:, 60*i);


        else

            newdata_str(: , 60*(i-1)+(i-1-1)*t_loss+ t_loss
+1 : 60*i+(i-1)*t_loss) = data_str(:, 60*(i-1)+1:60*i);
            newdata_str(:,60*i+(i-1)*t_loss  + 1) =
data_str(:, 60*i);
            newdata_str(:,60*i+(i-1)*t_loss  + 2) =
data_str(:, 60*i);

        end
```

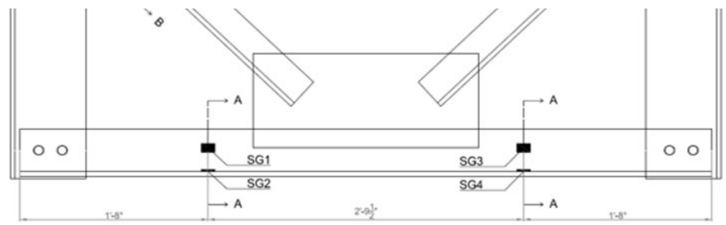
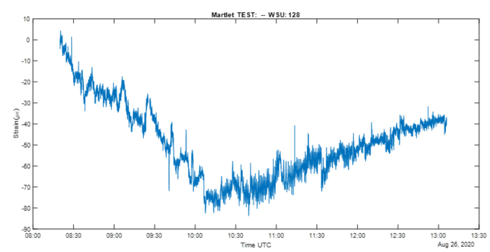
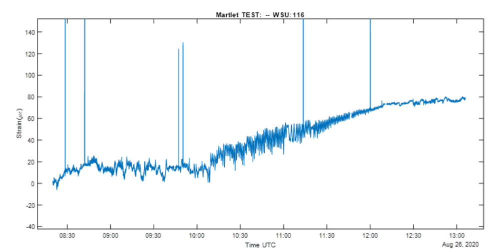
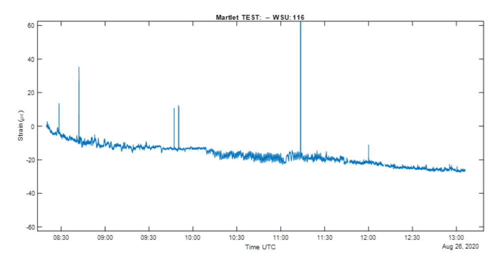
```
    else if t_loss == 3
            if i<=1
                newdata_str(:,1:60*i+(i-1)*t_loss) =
data_str(:, 1:60*i);
                newdata_str(:,60*i+(i-1)*t_loss  + 1) =
data_str(:, 60*i);
                newdata_str(:,60*i+(i-1)*t_loss  + 2) =
data_str(:, 60*i);
                newdata_str(:,60*i+(i-1)*t_loss  + 3) =
data_str(:, 60*i);

            else

                newdata_str(: , 60*(i-1)+(i-1-1)*t_loss+
t_loss +1 : 60*i+(i-1)*t_loss) = data_str(:, 60*(i-
1)+1:60*i);
                newdata_str(:,60*i+(i-1)*t_loss  + 1) =
data_str(:, 60*i);
                newdata_str(:,60*i+(i-1)*t_loss  + 2) =
data_str(:, 60*i);
                newdata_str(:,60*i+(i-1)*t_loss  + 3) =
data_str(:, 60*i);
            end
        end
    end
end



%% Plots
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200]);
plot(time, data_str(0+1,:), t, FBSG(:,0+1))
legend('martlet', 'cabled')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200])
plot(time, data_str(1+1,:), t, FBSG(:,1+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200])
plot(time, data_str(2+1,:), t, FBSG(:,2+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
```

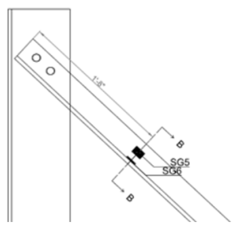
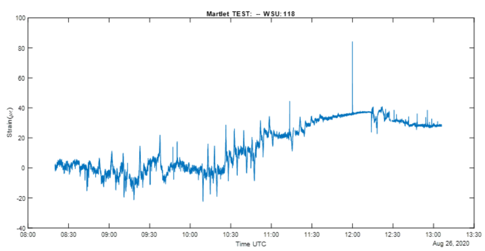
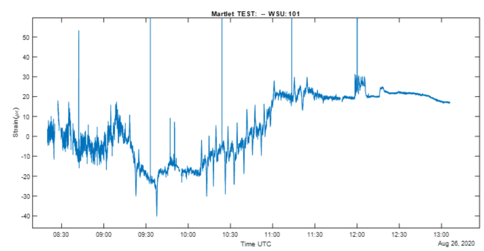
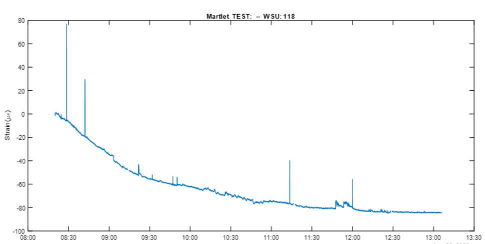
```
ylabel('strain (\mu\epsilon)')
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200])
plot(time, data_str(3+1,:), t, FBSG(:,3+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')

figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200]);
plot(time, data_str(4+1,:), t, QBSG(:,0+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200])
plot(time, data_str(5+1,:), t, QBSG(:,1+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200])
plot(time, data_str(6+1,:), t, QBSG(:,2+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200])
plot(time, data_str(7+1,:), t, QBSG(:,3+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')




%% Plots (with new data for time compensation)
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200]);
plot(newtime, newdata_str(0+1,:), t, FBSG(:,0+1),
'LineWidth',1.5)
legend('martlet M_0', 'cabled FBSG_0','FontSize', 10)
xlabel ('time (sec)','FontSize', 18)
ylabel('strain (\mu\epsilon)','FontSize', 18)
ax = gca;
ax.FontSize = 14;
```

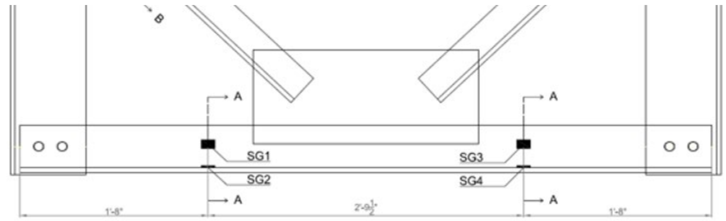
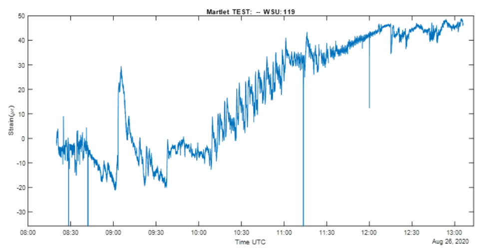
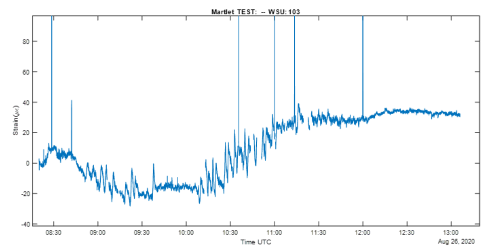
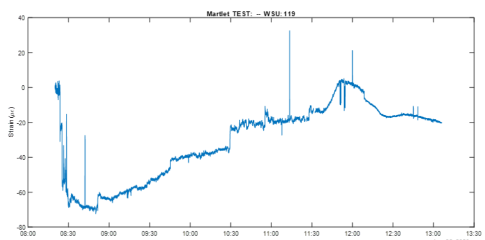
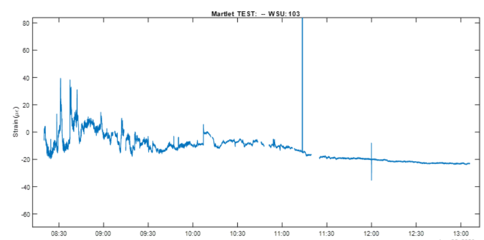
```
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200])
plot(newtime, newdata_str(1+1,:), t, FBSG(:,1+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200])
plot(newtime, newdata_str(2+1,:), t, FBSG(:,2+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')
figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200])
plot(newtime, newdata_str(3+1,:), t, FBSG(:,3+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')

figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200]);
plot(newtime, newdata_str(4+1,:), t, QBSG(:,0+1))
legend('martlet', 'NI')
xlabel ('time (sec)')
ylabel('strain (\mu\epsilon)')

figHand(i) = figure;
set (figHand(i), 'Position',[200 200 600 200])
plot(newtime, newdata_str(5+1,:), t, QBSG(:,1+1),
'LineWidth',1.5)
legend('martlet M_5', 'cabled QBSG_1','FontSize', 10)
xlabel ('time (sec)','FontSize', 18)
ylabel('strain (\mu\epsilon)','FontSize', 18)
ax = gca;
ax.FontSize = 14;
```

APPENDIX D: RAW DATA

Bay 1 (between external and internal girders) (LD | RD)	
	
Left Diagonal Member Strain Gauge 5	Right Diagonal Member Strain Gauge 7
	
Left Diagonal Member Strain Gauge 6	Right Diagonal Member Strain Gauge 8
	

<table>
<tr><td colspan="2">Bay 1 (between external and internal girders) (LBM | RBM)

</td></tr>
<tr><td>Bottom Member (Left) Strain Gauge 1

</td><td>Bottom Member (Right) Strain Gauge 3

</td></tr>
<tr><td>Bottom Member (Left) Strain Gauge 2</td><td>Bottom Member (Right) Strain Gauge 4

</td></tr>
</table>

<table>
<tr><td colspan="2">Bay 3 (between two internal diaphragms) (LD | RD)

</td></tr>
<tr><td>Left Diagonal Member Strain Gauge 5

</td><td>Right Diagonal Member Strain Gauge 7

</td></tr>
<tr><td>Left Diagonal Member Strain Gauge 6

</td><td>Right Diagonal Member Strain Gauge 8</td></tr>
</table>

<table>
<tr><td colspan="2">Bay 3 (between two internal diaphragms) (LBM | RBM)

</td></tr>
<tr><td>Bottom Member (Left) Strain Gauge 1

</td><td>Bottom Member (Right) Strain Gauge 3

</td></tr>
<tr><td>Bottom Member (Left) Strain Gauge 2

</td><td>Bottom Member (Right) Strain Gauge 4

</td></tr>
</table>

APPENDIX E: CONCRETE CONSTRUTION LOAD CALCULATIONS

```
TW1 = 81.5; % in

Length = 1500; %in

thickness = 7.375; %in

totalVolume = TW1 * Length * thickness / 12^3; %ft^3

weightDensity = 150; % lb/ft^3 for reinforced concrete, using the upper limit;

totalLoad = weightDensity * totalVolume; %lb

bulbTeeTop = 3 * 12 + 6; % in

surfaceArea = Length * bulbTeeTop; % in^2

pressure = totalLoad / surfaceArea; % lb/in^2 ie psi
```

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