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ATLSS Report No. 06-07

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Interim Report

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EXECUTIVE SUMMARY

The Pearl Harbor Memorial Bridge is located in Montgomery County, PA and carries I-476 traffic over the Schuylkill River, Norfolk Southern Railroad, a bike path, SEPTA, River Road, and Conshohocken Road.

The bridge has experienced some cracking in its superstructural elements. Field measurements were conducted to evaluate the global behavior of the bridge as a system as well as the local behavior of the cracked and uncracked details such that the possible cause of cracking could be examined. The data was collected by installing weldable resistance strain gages, bondable resistance strain gages, and displacement sensors at key locations in Span 12 of the south bound bridge.

Controlled crawl, dynamic, and parked, load tests using test truck of known weight and geometry were conducted. In addition, monitoring of the strain gages under random traffic was performed for a period of approximately 18 days. Data collected during monitoring was used to develop stress-range histogram for selected gages. This report summarizes the results of field instrumentation, controlled load test, and monitoring.

1.0 Introduction

The Pearl Harbor Memorial Bridge, north bound and south bound, are a dual fifteen span multi-girder and plate girder bridges. The bridge is located in Montgomery County, PA and carries I-476 traffic over the Schuylkill River, Norfolk Southern Railroad, a bike path, SEPTA, River Road, and Conshohocken Road. The north bound and south bound bridges are not identical due to the horizontal curvature of the bridges and the fact that more piers are needed on the south bond bridge. Figure 1.1 shows both the north and south bound bridges looking south. The south bound bridge, which is the focus of this study, has a total length of 2010'-0". The bridge features 8 spans of continuous welded deck girders, 5 spans of simply supported welded multiple I-beams and 2 spans of continuous multiple welded I-beams that feature a welded I-beam cross girder. Of specific interest to this study is Span 12and Span 13. These spans are a two span continuous stringer system with cross bracing system connecting the stringers. Figure 1.2 shows the super structural system of span 12. The length of Span 12 is 110'-9" and the length of Span 13 is 109'-3".

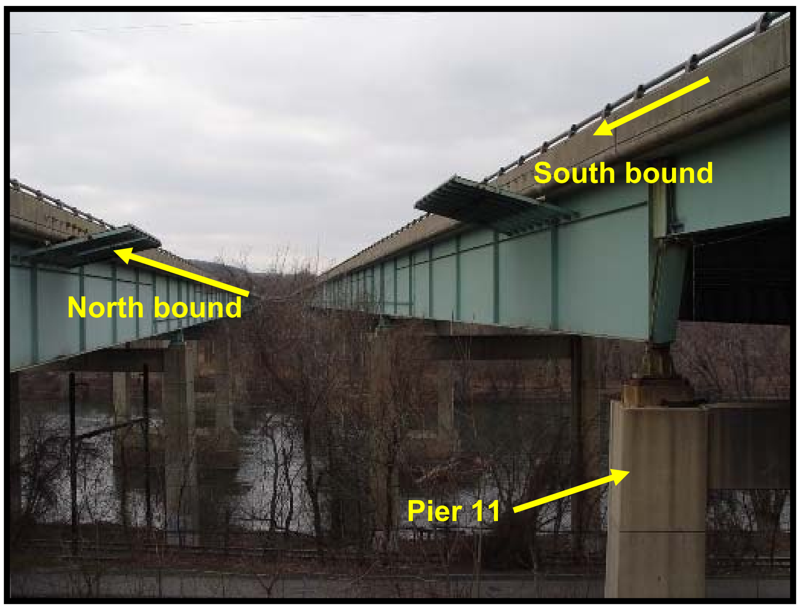


Figure 1.1 – Elevation view of the north bound and south bound bridges over the Schuylkill River

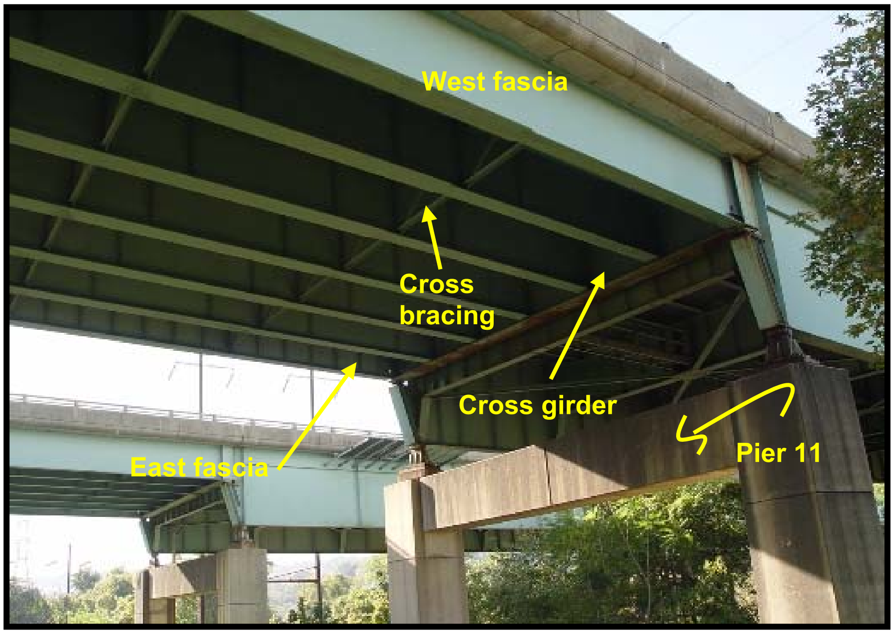


Figure 1.2 – Superstructural system of Span 12

The bridge was opened to traffic in the 70's and have experienced some cracking in its superstructural elements. For example, cracks are located in some stringer webs and in the web of the floorbeam under the deck joints. In Span 12, cracks are located in the web of both the east and west fascia stringers and appeared to have originated from the cope in the stringer flange. An example of such crack can be seen in Figure 1.3, which shows the crack in the web of the west fascia stringer. Cracks are also located at the web gap of the cross girder at pier 11 at the cross girder-to-west fascia (Stringer S7) connection. The web gap is defined by the small segment of the cross girder web between the cross girder flange and the end toe of the vertical weld attaching the transverse connection plate to the web of the cross girder. Under live load, the small web gap size could give rise to high secondary stresses, which could result in out-of-plane distortional fatigue cracking, which typically form at the toe of the vertical weld connecting the connection plate to the cross girder web. Cracks could also form at the toe of the horizontal weld used for attaching the flange and the web of the cross girder. Both type of cracks are present on the web of the cross girder at the cross girder-to-west fascia stringer connection at pier 11 (Figure 1.3)

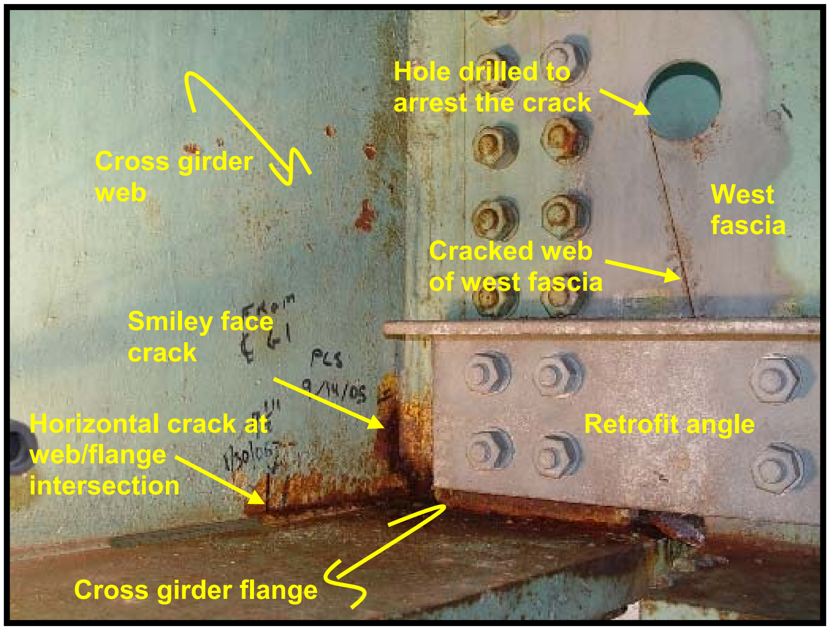


Figure 1.3 – Cracked web of the west fascia stringer (Stringer S7) and cracked web of the cross girder at pier 11

The objective of this study is to conduct field measurements to evaluate the global behavior of the bridge as a system as well as the local behavior of the cracked and uncracked details such that the possible cause of cracking could be examined. In addition to the field study, a detailed finite element model will be developed to aid in the process of recommending effective retrofit strategies to stop the current cracks from propagating further and to minimize the likelihood of new crack development at similar locations on the bridge. In order to evaluate the effectiveness of the repairs and to estimate the remaining fatigue life of the retrofitted details, post-repair controlled load testing and long-term monitoring will be conducted. Field measurements were conducted in Span 12 with most of the instrumentation located near pier 11.

The first step of the study was completed through short-term (approximately 18 days) monitoring of Span 12 and Span 13 under random live loading. The monitoring was necessary in examining the global behavior of the instrumented span and the local behavior of the details in question to random daily traffic. In addition to short term monitoring, controlled load tests were conducted to investigate the response of the instrumented details to load with known weight. The results of the controlled load tests will be used for the calibration of the finite element model, which will be developed and used in the process of recommending effective retrofit strategies aimed to mitigate the out-of-plane distortion cracking problems.

All of the field work for the short term monitoring and controlled load testing was conducted over the period between January and February, 2006 by the team from the ATLSS Engineering Research Center at Lehigh University, Bethlehem, PA.

2.0 Instrumentation Plan and Data Acquisition

The same instrumentation plan was used for both the controlled load testing and the short-term monitoring as described in the following section. Instrumentation was installed in span 12, with the majority of the instrumentation located near pier 11. A detailed description of the location of the strain gages and the Linear variable differential transducers (LVDT's) instrumented on the spans can be found in Appendix A.

2.1 Strain Gages

Strain gages were installed to establish the global and local behavior of the bridge at both cracked and uncracked locations. The majority of the strain gages installed in the field was produced by Measurements Group Inc. and had 0.25 inch gage length, model LWK-06-W250B-350. These gages are uniaxial weldable resistance-type strain gages. The weldable gages were pre-bonded to a metal strip by the manufacturer and spot welded to the tested structure in the field. The gages resistance is 350Ω and an excitation voltage of 10 volts was used.

When the web gap size was less than 1/4", bondable strip gages were used in order to capture the stress gradient of the web gap due to web distortion. The strip gages were type QFXV-01-11-002LE manufactured by TML Tokyo Sokki Kenkyujo Co. Ltd., and distributed by Texas Measurements. Each strip gage contains five 120 ohm gages with a grid length of 1.0 mm. An excitation voltage of 5 volts was used.

The metal surfaces were ground and cleaned before installing the weldable and the bondable gages. After installation, gages were covered with a multi-layer protective system then sealed with silicon type agent.

2.2 Displacement Sensors

Linear variable differential transducers (LVDTs) were mounted to magnetic bases installed on the bridge. The sensors, manufactured by Macro Sensors, have a displacement range of 1/4 inch with infinite resolution. The resolution of the measurement is limited by the data acquisition system. As configured during this study, the resulting resolution was better than 0.01 mils. The sensors are encased in stainless steel housings and are suitable for use in harsh environments.

2.3 Data Acquisition

A Campbell Scientific CR9000 Data Logger was used for the collection of the data throughout the controlled testing and short-term monitoring. The logger is a high-speed, multi-channel, 16-bit system configured with digital and analog filters to assure noise-free signals. Real-time data were viewed while on sight by connecting the logger directly to a laptop computer. This was done in order to assure that all sensors were functioning properly and to review the response of the bridge during testing when data collection was started and stopped manually using the laptop.

The CR9000 data logger was enclosed in a weather-tight box at pier 11, as seen in Figure 2.1 Figure 2.2 contains a photograph of the inside of the box. In addition to the CR9000 data acquisition system, a power conditioner was used to provide protection against surge in power.

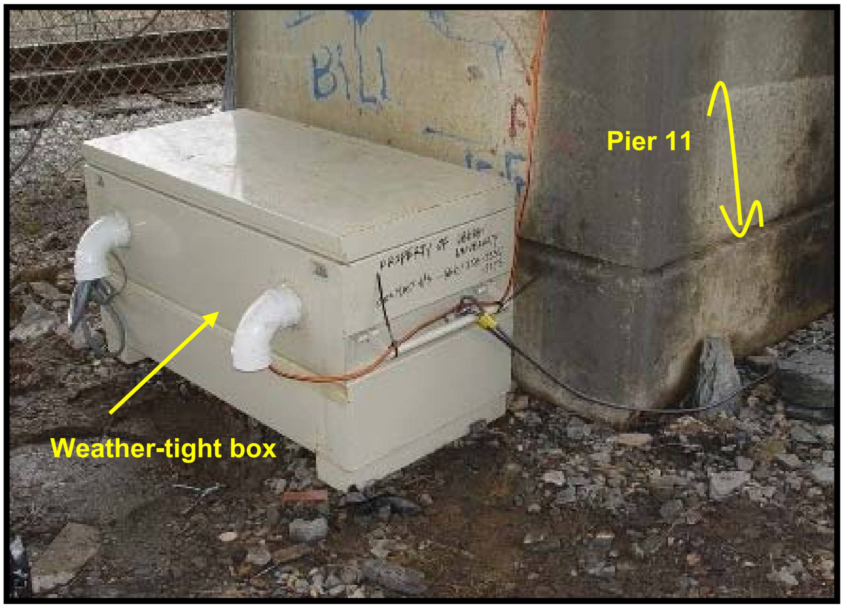


Figure 2.1 – Weather-tight enclosure containing data acquisition system

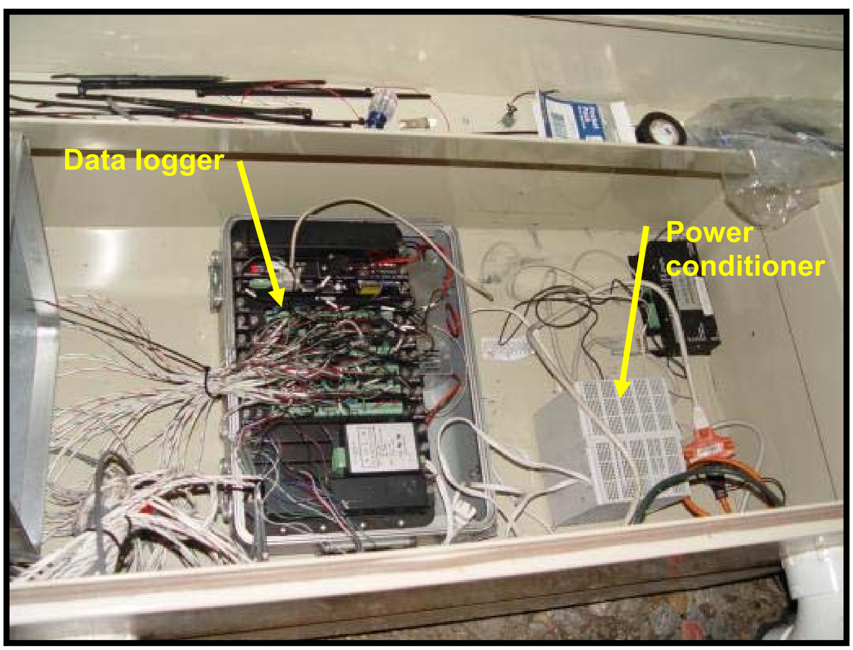


Figure 2.2 – Data acquisition system

Remote communications with the data logger was established using a wireless modem. Data download was performed automatically via a server located in the ATLSS laboratory in Bethlehem, PA. This link was also used to upload new programs as needed. Data were collected and reviewed periodically throughout the monitoring period to assure the integrity of the data.

2.4 Remote Short-term Monitoring

The CR9000 data logger remained in place and was used for short-term monitoring of the bridge. During the remote monitoring phase, both time history data and stress-range histograms were recorded.

To minimize the volume of data collected during recording of the stress-time-history files, data were not recorded continuously. A predefined lower limit stress value (i.e., trigger) for two gages was used to control when recording of the data began and ended. Once the strain value for that gage reached the predefined limit, the logger began recording data for all sensors on the bridge. Gages used to trigger the recording of data were selected so that southbound traffic in each lane could be identified and stored in separate files.

Remote communication with the logger was established using a wireless cellular modem. The remote communication allowed program upload and data download to be performed from the ATLSS Research Center in Bethlehem, PA.

2.5 Electrical Power

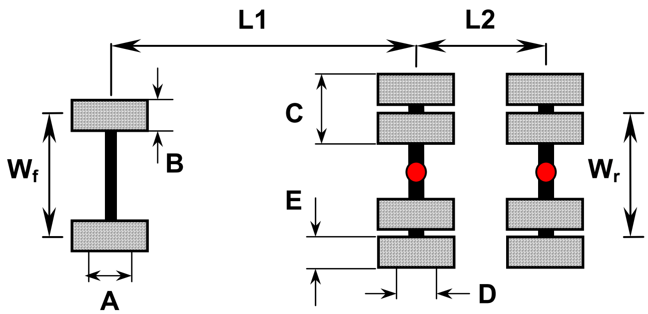
An electric power connection was made to a PENNDOT control cabinet at Mile 17 1/10 through the installation of a junction box on pier 11. The 110V-20A circuit was necessary to energize the data logger and sensors during the project. A power wire was strung along pier 11 of the south bound bridge down to the data acquisition box. Figure 2.3 illustrates the location of the junction box on pier 11.

Figure 2.3 – Power supply junction box on pier 11

3.0 Controlled Load Testing

A series of controlled load tests were conducted on February 9, 2006 and continued into early morning of February 10, 2006. The test truck was a three axle truck and fully loaded with gravel. The gross vehicle weight (GVW) of the truck was 59,800 pounds. Figure 3.1 shows the truck. The geometry and the axle load data of the test truck are listed in Table 3.1 and Table 3.2, respectively.

Figure 3.1 – Test truck used in the controlled load testing



Rear Axle	L1 (in)	L2 (in)	L3[1] (in)	L4[1] (in)	W_f (in)	W_r (in)	A[1] (in)	B (in)	C (in)	D[1] (in)	E (in)
Tandem	164	51	-	-	87	73	-	13	22	-	9

Note:
1. Parameter not needed

Table 3.1 – Geometry of test truck used in the controlled load tests

Test Description	Rear Axle Type	Front Axle Load (lb)	Rear Axle Group Load (lb)	GVW[1] (lb)	Date of Tests
Controlled Load Tests	Bi-axle	14,050	45,750	59,800	February 9, 2006

Note:
1. GVW = Gross Vehicle Weight

Table 3.2 – Axle load data of test truck

The controlled load tests were conducted on Thursday, February 9 and Friday, February 10, 2006 between 11 PM and 1 AM. Prior to each test, traffic was stopped approximately 4 miles north of the bridge by Pennsylvania State Patrol to eliminate any disruption to the test that could be caused by other traffic passing over the bridge during testing, and to assure that the response measured in the instrumented channels is caused only by the test truck traveling over the spans.

The tests consisted of a series of six crawl tests, one static parked test which was conducted during one of the crawl tests, and three dynamic tests. In all tests the truck traveled in the south bound direction. The crawl tests started at the north abutment and the test truck was driven at approximately 5 miles per hour across the bridge. Two crawl tests were conducted during each 10 minute period of stopped traffic time. After the truck drove over Span 13 and Span 12, it reversed and started at the north abutment again for the second test. The test truck then circled around for the next two tests in order to let traffic dissipate. For example, the test truck was positioned at the north abutment and traveled over Span 12 and Span 13 in the right lane in the crawl test CRL_R1. The truck went in reverse and was repositioned at the north abutment again to conduct the second test CRL_R2 with the truck traveling over Span 13 and Span 12 in the right lane. The dynamic tests were conducted in the south bound direction with the truck traveling at speeds of approximately 60 miles per hour across the spans. One dynamic test was completed during each traffic stoppage due to the large distance required for the truck to attain high speed.

As mentioned above, testing was conducted across the bridge in all three lanes. A total of six crawl tests were conducted. The first two crawl tests were conducted with the test truck traveling in the right lane at a speed of 5 miles per hour. In the third and fourth tests, the test truck traveled at 6 miles per hour in the middle lane. The fourth crawl test included a parked test where the test truck completely stopped on Span 12 at predetermined locations. The reason for conducting the parked test was to measure the response of the instrumented channels to the test truck with known weight at known locations on the spans. The information was needed for the calibration of the finite element model which is used to investigate possible retrofit schemes of the cracked floorbeam. The test truck was completely stopped in Span 12 at two locations for 10 seconds at each location. The locations were illuminated by glow sticks as shown in Figure 3.2. The locations were at the parapet break located approximately 22’-2” north of pier 11 and at the parapet break near midspan approximately 46’-15 ¼” south of pier 11. In the fifth and sixth tests, the test truck traveled at 5 miles per hour in the left lane.

A total of three dynamic tests were conducted. Each lane had one dynamic test completed in it starting with the right lane and ending with the left lane. All tests were conducted at 60 miles per hour.

A summary of the controlled load tests data are presented in Table 3.1

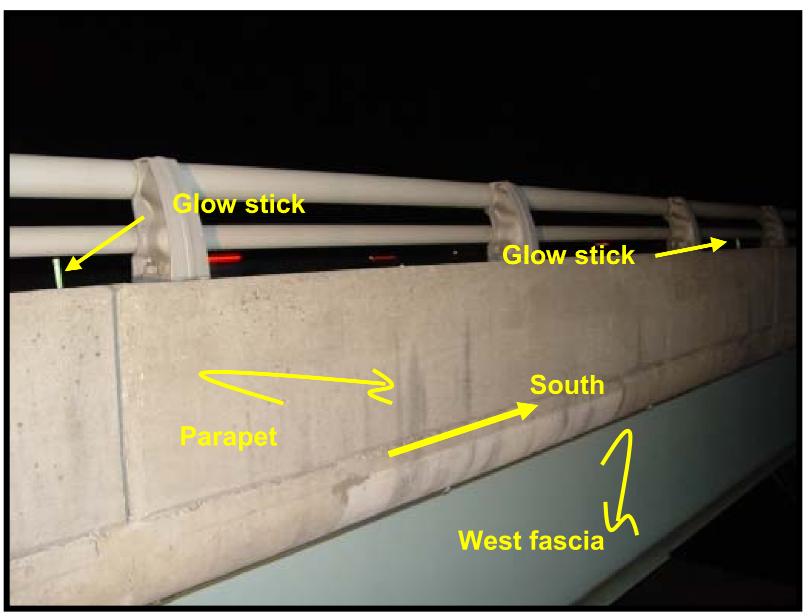


Figure 3.2 - Illuminated glow sticks marking the locations for the test truck to stop at in Span 12 in the parked test during the fourth crawl test

Test no.	Test type	Location	Direction	File Name	Time	Speed (mph)
1	Crawl	Right	SB	CRL_R1	11:13	5
2	Crawl	Right	SB	CRL_R2	11:15	5
3	Crawl	Middle	SB	CRL_M1	11:33	6
4	Crawl & Parked	Middle	SB	CRL_M2	11:38	6
5	Crawl	Left	SB	CRL_L1	11:55	5
6	Crawl	Left	SB	CRL_L2	11:57	5
7	Dynamic	Right	SB	DYN_R1	12:12	60
8	Dynamic	Middle	SB	DYN_M1	12:25	60
9	Dynamic	Left	SB	DYN_L1	12:40	60

Table 3.1 – Summary of the controlled load tests

4.0 Summary of Instrumentation Layout

The following section summarizes the instrumentation plan used on the bridge. Detailed instrumentation plans are included in Appendix A.

4.1 Strain Gages on Stringers

4.1.1 Top and Bottom Flange of Stringer

Strain gages were installed on the top and bottom flange of stringers S1, S3, and S6 to measure the nominal bending stress in the stringers near the cross girder-to-stringer connection at Pier 11 and near midspan of Span 12. To measure the nominal stresses near the cross girder-to-stringer connection, strain gages CH_6, CH_15, and CH_24 were installed on the top flange of stringer S1, S3, and S6, respectively, at 6 inches from the stringer top flange cope. Strain gages CH_7, CH_16, and CH_25 were installed on the bottom flange of stringers S1, S3, and S6, respectively, aligned with gages CH_6, CH_15, and CH_24. Strain gages were also installed on the top and bottom flange of stringer S1, S3, and S6 near midspan where strain gages CH_8, CH_17, and CH_26 were installed on the bottom face of the top flange of stringers S1, S3, and S6, respectively, and strain gages CH_9, CH_18, and CH_27 were installed on the bottom flange of S1, S3, and S6, respectively, aligned with gages CH_8, CH_17, and CH_26. Figure 4.1 shows strain gages CH_17 and CH_18 installed on the top and bottom flange, respectively, of stringer S3 in Span 12 near midspan.

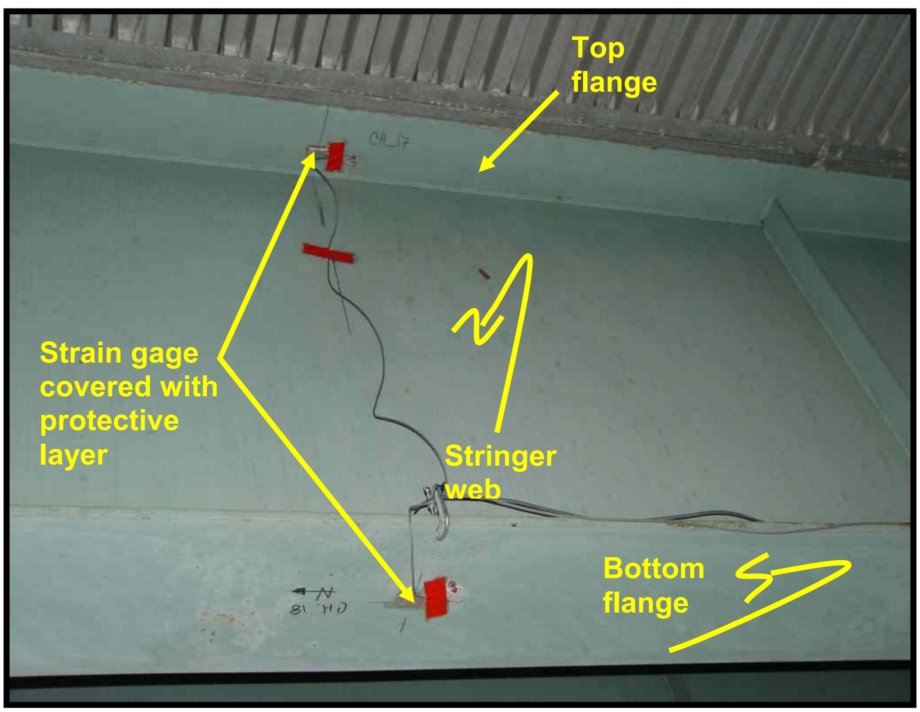


Figure 4.1 – Strain gages CH_17 and CH_18 installed on the top and bottom flange, respectively, of stringer S3 in Span 12 near midspan

4.1.2 Fascia Stringer Retrofit Connection Angle

Strain gages were installed on the leg of the retrofit angles connecting the web of the east and west fascia stringer to the connection plates welded to the cross girder web. The angles were previously installed to provide positive attachment between the fascia stringers and the cross girders in an attempt to reduce the driving force responsible for fascia stringer cope cracking. Specifically, CH_10 on the angle located at the east fascia and CH_19 on the angle located at the west fascia stringer. The gages were installed at a distance of approximately 10" away from the south end of the angle and at mid height of the bolted leg. Figure 4.2 shows strain gage CH_10 installed on the retrofit angle of the east fascia stringer.

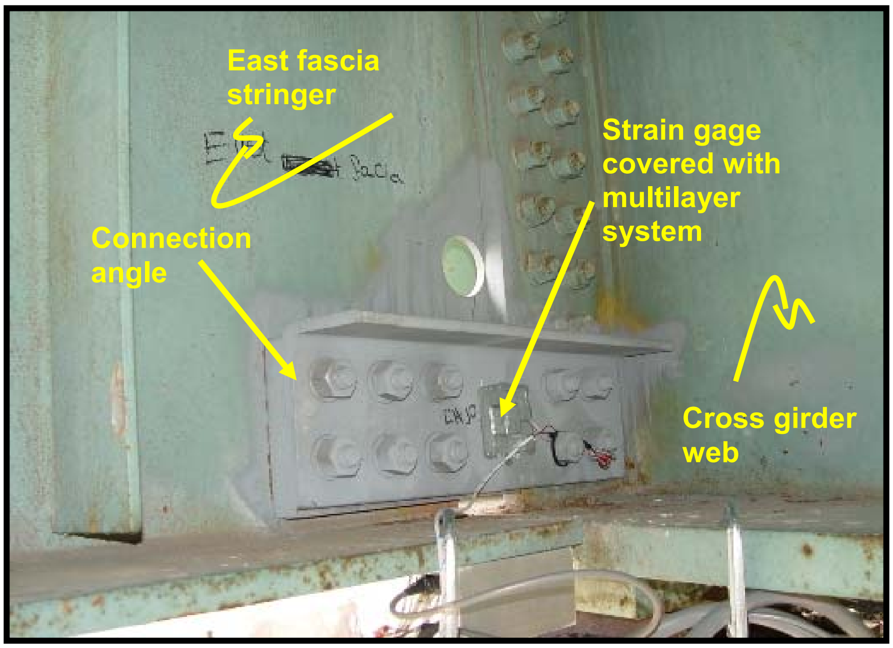


Figure 4.2 – Strain gages CH_10 installed on the retrofit angle of the east fascia

4.2 Strain Gages on Cross Girder at Pier 11

4.2.1 Web Gap of Cross Girder at Interior Stringers

Two strain gages were installed in the web gap of the cross girder at interior stringers S3 and S6, on both faces of the cross girder web, to measure the stresses in the web gap and assess its vulnerability to develop cross girder cracks similar to those developed at the west fascia. On the north face, a large web gap of approximately 6 inches exists at the cross girder-to-stringer connection at both stringers. On the other face of the web, web gaps of approximately 5/8" exist at the transverse stiffener welded to the cross girder web. Two pairs of strain gages were installed back-to-back and directly above each other at these web gaps. The gages were first installed directly above each other on the south face of the web at the web gap of the transverse stiffener detail and fit tight against the horizontal weld attaching the web to the bottom flange of the cross girder and the vertical weld attaching the transverse stiffener to the web of the cross girder. Two gages were installed on the north face of the web at the 6 inches web gap by directly projecting the gages previously installed on south face of the web. The web gaps on the cross girder at interior stringers S3 and S6 were chosen for the installation of the gages. At interior stringer S3, strain gage CH_14 was installed in the web gap on the south face of the gross girder web and fit tight against the horizontal and vertical welds as mentioned above. Strain gage CH_13 was installed directly above strain gage CH_14. Strain gages CH_12 and CH_11 were installed on the north face of the web by directly projecting strain gage CH_14 and strain gage CH_13, respectively. At interior stringer S6, strain gage CH_23 was installed in the web gap on the south face of the gross girder web and fit tight against the horizontal and vertical welds as mentioned above. Strain gage CH_22 was installed directly above strain gage CH_23. Strain gages CH_21 and CH_20 were installed on the north face of the web by directly projecting strain gage CH_23 and strain gage CH_22, respectively. Figure 4.3 shows strain gages CH_11 and CH_12 installed on the north face of the cross girder web at the 6 inches web gap of the transverse connection plate detail at interior stringer S3.

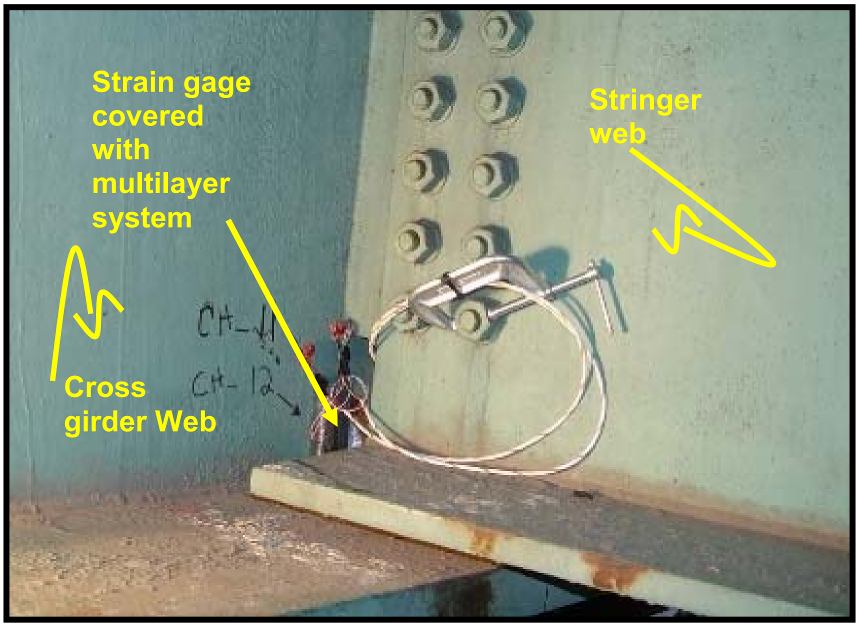


Figure 4.3 – Strain gages CH_11 and CH_12 installed on the north face of the cross girder web at the 6 inches web gap of the transverse connection plate detail at interior stringer S3

4.2.2 Web Gap of Cross Girder at East Fascia Stringer

Small web gap sizes exist on the web of the cross girder at the cross girder-to-fascia stringer connection unlike those located at the cross girder-to-interior stringer connection. At the east fascia, the vertical weld used to attach the connection plate to the web of the cross girder ran the full depth of the cross girder web and there is practically no web gap. Therefore, the strip gages were installed adjacent to the vertical weld attaching the connection plate to the web of the cross girder and fit tight against the horizontal weld attaching the web and the flange of the cross girder. The gages installed adjacent to the zero inches web gap were strain gages CH_1 through CH_5 where gage CH_1 is the top gage and gage CH_5 is the bottom gage as shown in Figure 4.4.

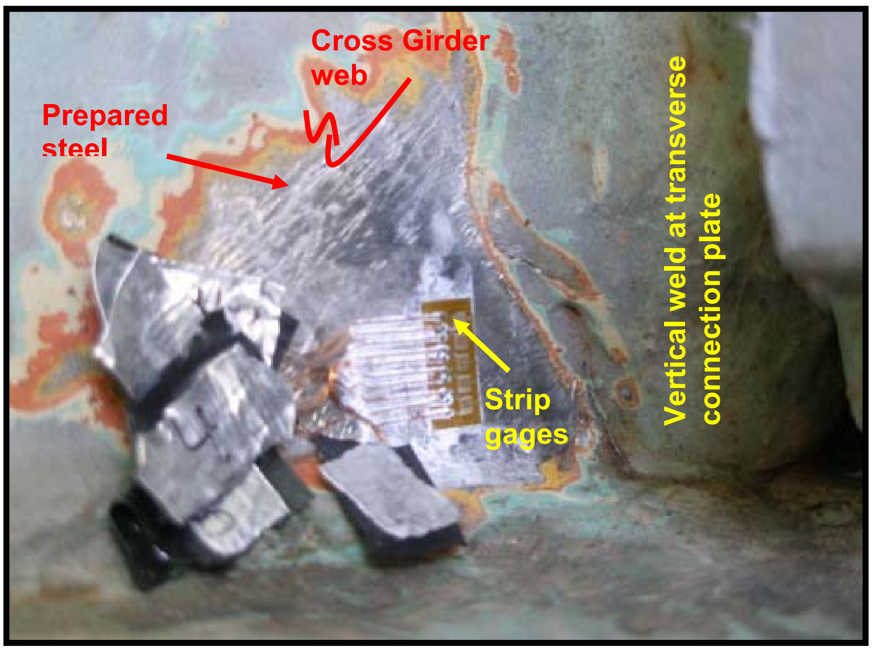


Figure 4.4 – Strip gages CH_1 through CH_5 installed on the north face of the cross girder web adjacent to the zero inches web gap of the transverse connection plate detail at the east fascia

4.2.3 Cross Girder Web near Existing Cracks at the Cross Girder-to-West Fascia Connection

Strain gages were installed near the existing cracks located on the cross girder web at the west fascia to measure the nominal stresses around the cracks and estimate the driving force, which could be responsible for the development and the propagation of the cracks. Specifically, strain gages CH_28 and CH_29 were installed vertically on the south and north face, respectively, of the cross girder web 3 inches away from the existing longitudinal crack along the toe of the horizontal weld used for attaching the flange and the web of the cross girder. Strain gages CH_30 and CH_31 were installed horizontally on the south and north face, respectively, of the cross girder web 3 inches away from the "smiley face" crack which originated at the toe of the vertical weld connecting the connection plate to the cross girder web. Figure 4.5 shows strain gages CH_29 and CH_31 installed on the north face of the cross girder web near the existing cracks.

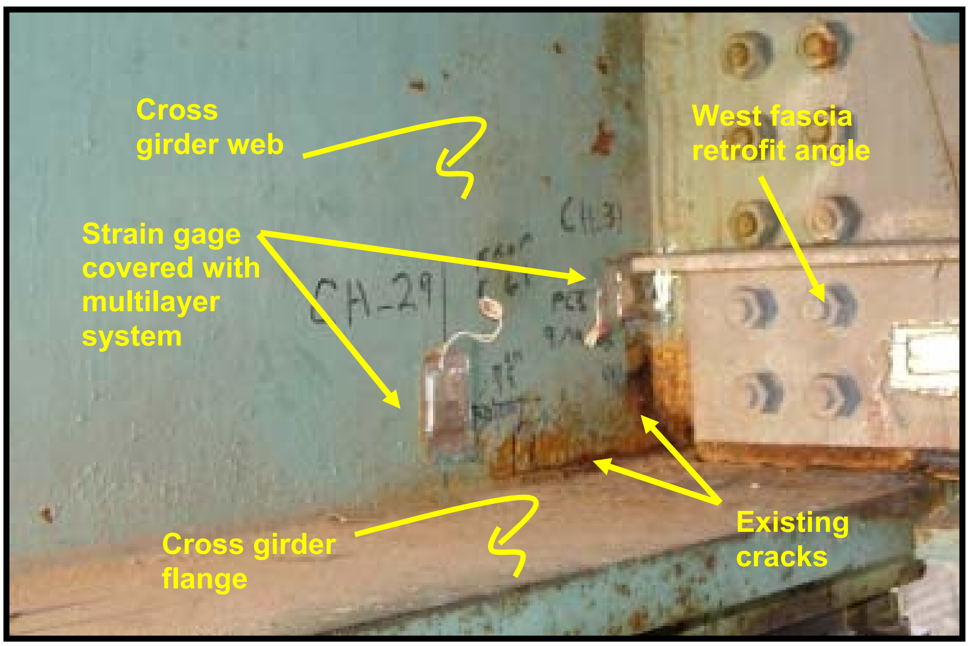


Figure 4.5 – Strain gages CH_29 and CH_30 installed on the north face of the cross girder web near the existing cracks

4.3 Displacement Sensors at Cross Girder Web Gaps

Three LVDT's were installed to measure the relative displacement between the cross girder bottom flange and the bottom flange of the fascia and interior stringers. Specifically, LVDT's CH_32 and CH_34 were installed to measure the relative displacement between the cross girder and the east and west fascia, respectively. Similar measurement was taken at interior stringer S3 using LVDT CH_33. The LVDT's were installed to explore the out-of-plane bending behavior of the cross girder web and to compare between the relative displacement between the cross girder and the stringers at the three different locations. Figure 4.6 shows LVDT CH_33 installed to measure the relative displacement between the bottom flange of interior stringer S3 and the bottom flange of the cross girder.

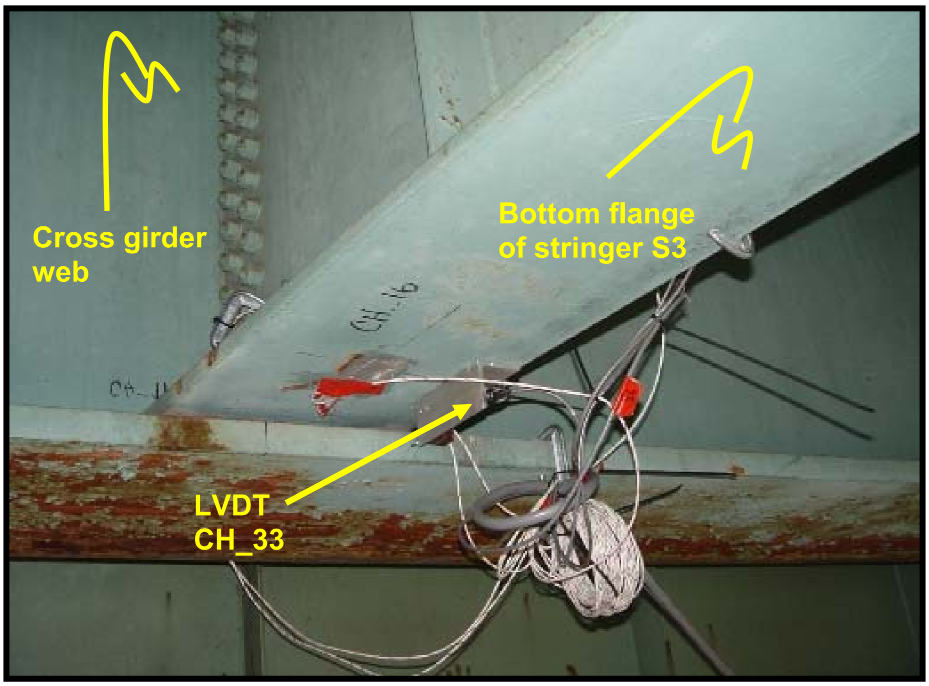


Figure 4.6 – LVDT CH_33 installed to measure the relative displacement between the bottom flange of interior stringer S3 and the bottom flange of the cross girder.

5.0 Results of Controlled Load Tests

The results of the controlled static and dynamic load tests are discussed in this section.

5.1 General Response

In general, the response of the instrumented span was as expected and typical of a two span continuous bridge. Figure 5.1 presents the response of strain gage CH_17 installed on the bottom face of the top flange and strain gage CH_18 installed on the bottom flange of stringer S3 near midspan at a distance of approximately 55'-4 1/2" north of pier 11 as the test truck crossed over Span 13 and Span 12 in the left lane in the south bound direction in the crawl test CRL_L2. As shown in the figure, compressive stresses were measured in strain gage CH_18 as the test truck traveled over Span 13. The stresses became tension as the test truck passed over Span 12. Furthermore, the figure shows low response in strain gage CH_17 as the test truck crossed over the span, indicating that the instrumented span is behaving compositely although the bridge was not designed for composite action between the deck and the stringers.

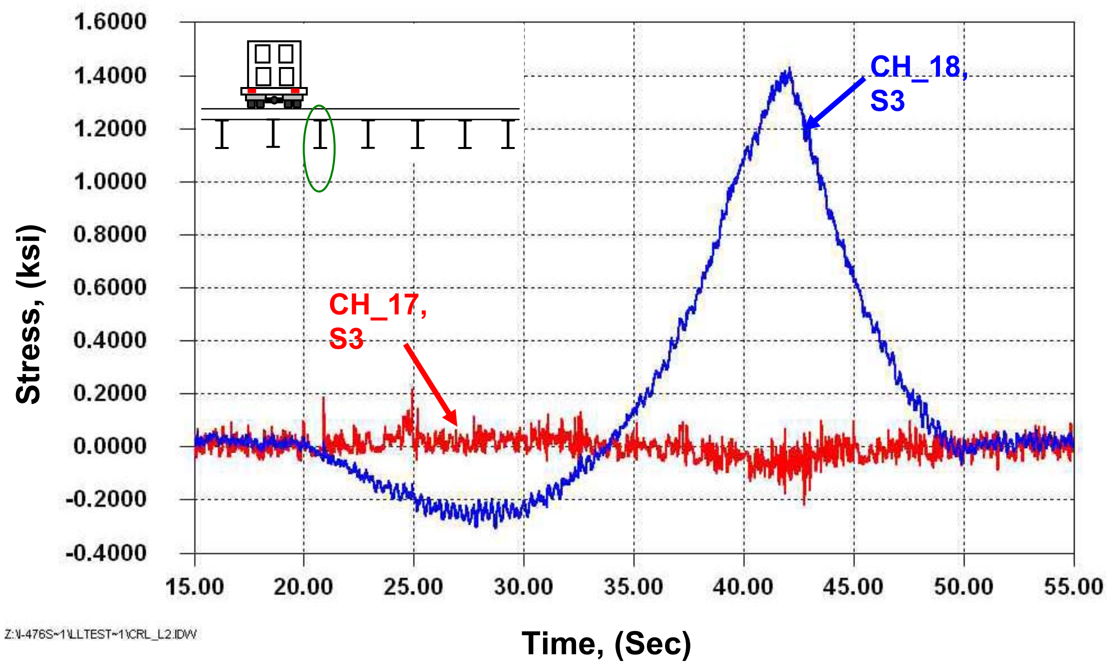


Figure 5.1 – Response of CH_17 and CH_18 installed on the top and bottom flange of stringer S3 near midspan of Span 12 at a distance of approximately 55'-4 1/2" north of Pier 11 as the test truck passed in the left lane in the crawl test (CRL_L2)

Another characteristic of the behavior of the instrumented span is load distribution between the stringers. As seen in Figure 5.2, similar response was observed in strain gages CH_9 installed near midspan on the bottom flange of the east fascia stringer and strain gage CH_18 installed near midspan on the bottom flange of stringer

S3. This could be attributed to the situation that the test truck was located about half way between stringer S1 and S3. As expected, low response was observed in strain gage CH_27 installed on the bottom flange of stringer S6 since the stringer is further away from the test truck.

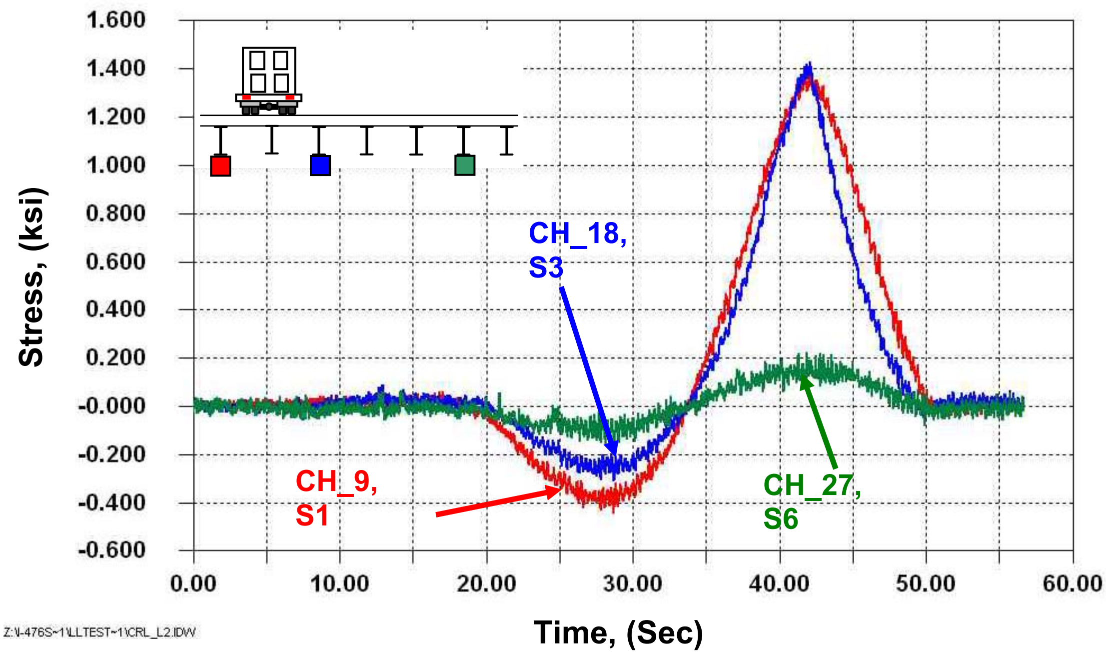


Figure 5.2 – Response of strain gages CH_9, CH_18, and CH_27 installed on the bottom flange of stringers S1 (east fascia), S3, and S6, respectively, near midspan of Span 12 at a distance of approximately 55'-4 1/2" north of Pier 11 as the test truck passed in the left lane in the crawl test (CRL_L2)

5.2 Repeatability of Data

All crawl tests were repeated. As previously discussed, a parked test was added to the crawl test (CRL_M2) such that the static response of the strain gages to the known weight could also be confirmed. Data obtained show consistency between the repeated crawl tests. With this confidence in the crawl run load test data and to minimize distribution to traffic, the dynamic tests were not repeated. The dynamic tests were conducted with the test truck traveling with a speed of 60 mph. The overall response of the instrumented gages was similar between the crawl and the dynamic tests.

5.3 Stresses in the Top and Bottom Flanges of the Stringers

As previously discussed, nominal bending stresses in the stringers were measured near the cross girder-to-stringer connection at Pier 11 by installing strain gages CH_6, CH_15, and CH_24 on the top flange of stringer S1, S3, and S6, respectively, at 6 inches from the stringer top flange cope and strain gages CH_7, CH_16, and CH_25 on the bottom flange of stringers S1, S3, and S6, respectively, below gages CH_6, CH_15, and CH_24. The nominal bending stresses in the stringers near midspan of Span 12 was also measured by installing strain gages CH_8, CH_17, and CH_26 on the bottom face of the top flange of stringers S1, S3, and S6, respectively, and strain gages CH_9, CH_18, and CH_27 on the bottom flange of S1, S3, and S6, respectively, below gages CH_8, CH_17, and CH_26.

Figure 5.1 and Figure 5.2 show that the behavior of the instrumented span is typical of two-span continuous. A summary of the maximum stress, minimum stress, and stress range values experienced by the gages in the first crawl tests is presented in Table 5.1 and Table 5.2. The data clearly shows low measured stresses in the strain gages installed on the top flange of the stringers, implying a composite action between the stringers and the bridge deck although the bridge was not designed for such action. Furthermore, very low stresses were measured by the gages installed on the bottom flange of the stringers near the cross girder-to-stringer connection, suggesting that only a very low magnitude of flexural moment is transmitted between the stringer and the cross girder.

Span 12, near cross girder-to-stringer connection						
Truck in lane	Bottom flange (ksi) (CH_7, S1)			Top flange (ksi) (CH_6, S1)		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.1	-0.1	0.2	0.3	-0.1	0.4
Middle	0.0	0.0	0.0	0.0	0.0	0.0
Left	0.1	-0.1	0.2	0.0	-0.1	0.1

Span 12, near cross girder-to-stringer connection						
Truck in lane	Bottom flange (ksi) (CH_16, S3)			Top flange (ksi) (CH_15, S3)		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.1	0.0	0.1	0.1	0.0	0.1
Middle	0.1	0.0	0.1	0.1	0.0	0.1
Left	0.0	0.0	0.0	0.0	0.0	0.0

Span 12, near cross girder-to-stringer connection						
Truck in lane	Bottom flange (ksi) (CH_25, S6)			Top flange (ksi) (CH_24, S6)		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.0	0.0	0.0	0.0	0.0	0.0
Middle	0.0	0.0	0.0	0.0	0.0	0.0
Left	0.1	0.0	0.1	0.1	0.0	0.1

Table 5.1 – Summary of peak measured bending stresses, in the bottom and top flanges of stringers S1, S3, and S6 near the cross girder-to-stringer connection for the various truck test position in the first crawl tests CRL_R1, CRL_M1, and CRL_L1

Span 12, near midspan						
Truck in lane	**Bottom flange (ksi) (CH_9, S1)**			**Top flange (ksi) (CH_8, S1)**		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.1	-0.1	0.2	0.0	0.0	0.0
Middle	0.5	-0.2	0.7	0.0	0.0	0.0
Left	1.4	-0.4	1.8	0.0	0.0	0.0

Span 12, near midspan						
Truck in lane	**Bottom flange (ksi) (CH_18, S3)**			**Top flange (ksi) (CH_17, S1)**		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.6	-0.2	0.8	0.0	0.0	0.0
Middle	1.5	-0.3	1.8	0.0	0.0	0.0
Left	1.4	-0.3	1.7	0.0	0.0	0.0

Span 12, near midspan						
Truck in lane	**Bottom flange (ksi) (CH_27, S6)**			**Top flange (ksi) (CH_26, S6)**		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	1.5	-0.5	2.0	0.0	0.0	0.0
Middle	0.6	-0.2	0.8	0.0	0.0	0.0
Left	0.2	-0.1	0.3	0.0	0.0	0.0

Table 5.2 – Summary of peak measured bending stresses, in the bottom and top flanges of stringers S1, S3, and S6 near midspan for the various truck test position in the first crawl tests CRL_R1, CRL_M1, and CRL_L1

5.4 Stresses on the Leg of the Retrofit Angle at the Fascia Stringers

Strain gages CH_10 and CH_19 were installed on the leg of the retrofit angles connecting the web of the east and west fascia, respectively, to the connection plates welded to the cross girder web. Figure 5.3 shows the response of strain gages CH_10 and CH_19 installed on the leg of the angles at the east and west fascia, respectively, as the test truck passed over the middle lane in the crawl test (CRL_M1). The figure shows similar magnitude of stresses measured by both gages as the test truck approaches the location where the angles are located. The response differs in the angles as the test truck is near or directly above the angles. This could be associated with the existence of the cross girder cracks at the west fascia. A summary of the maximum stress, minimum stress, and stress range values experienced by the gages in the first crawl tests is presented in Table 5.3. For all three crawl tests, the angle at the west fascia stringer had higher stresses.

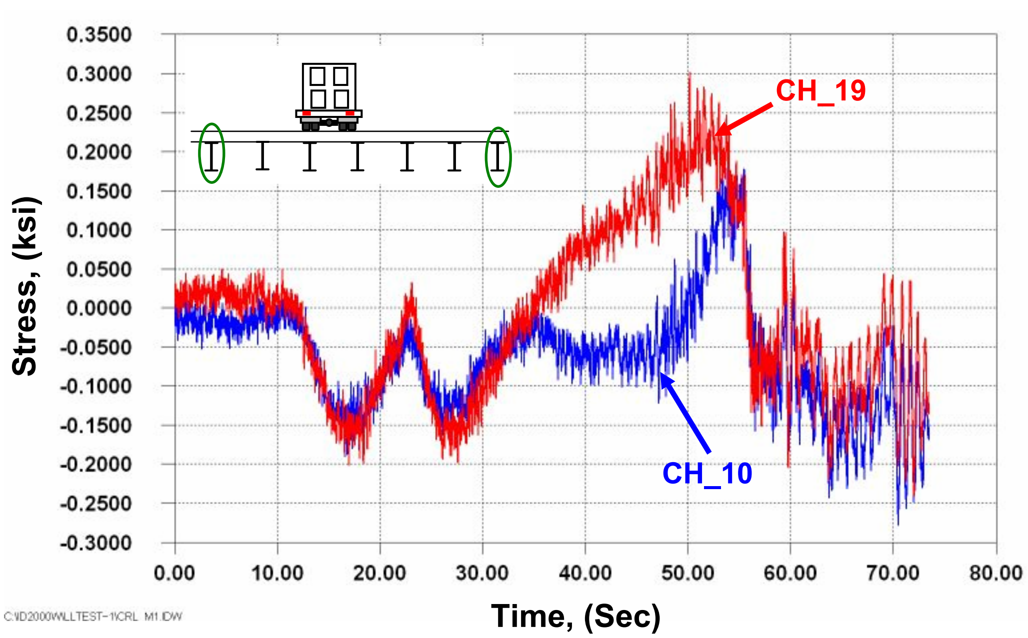


Figure 5.3 – Response of strain gages CH_10 and CH_19 installed on the leg of the angles connecting the web of the east and west fascia, respectively, to the connection plates welded to the cross girder web as the test truck passed in the middle lane in the crawl test (CRL_M1)

Span 12, on leg of retrofit angle						
Truck in lane	Angle at east fascia (ksi) (CH_10, S1)			Angle at west fascia (ksi) (CH_19, S6)		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.5	-0.2	0.7	0.1	-0.7	0.8
Middle	0.2	-0.2	0.4	0.3	-0.2	0.5
Left	0.1	-0.8	0.9	0.8	-0.3	1.1

Table 5.3 – Summary of peak measured stresses, in the leg of the angles connecting the web of the east and west fascia to the connection plates welded to the cross girder web for the various truck test position in the first crawl tests CRL_R1, CRL_M1, and CRL_L1

5.5 Stresses in the Web Gap of the Cross Girder at Interior Stringers

As previously mentioned, strain gages were installed in the web gap of the cross girder at interior stringers S3 and S6, on both faces of the web, to measure the stresses in the web gap. At interior stringer S3, strain gages CH_14 and CH_13 were installed in the web gap on the south face of the gross girder web at transverse stiffener detail. Strain gages CH_12 and CH_11 were installed in the web gap on the north face of the cross girder web at the cross girder-to-stringer connection by directly projecting strain gages CH_14 and CH_13, respectively. Similarly, at interior stringer S6, strain gages CH_23 and CH_22 were installed in the web gap on the south face of the gross girder web at transverse stiffener detail. Strain gages CH_21 and CH_20 were installed in the web gap on the north face of the cross girder web at the cross girder-to-stringer connection by directly projecting strain gages CH_14 and CH_13, respectively.

A summary of the maximum stress, minimum stress, and stress range values experienced by the gages in the first crawl tests is presented in Table 5.4. The table shows low stresses measured by the gages. As expected, the stresses measured by strain gage CH_21 installed at interior stringer S6, although low, were higher than those measured by strain gage CH_12 installed at similar location at interior stringer S3 (Figure 5.4). This is an indication of an increase in the out-of-plane distortion stresses in the web gap areas from the interior to the fascia stringer. The maximum recorded stress range at the web gap of the cross girder at the interior stringer is 2.7 ksi due to the crawl runs of the test truck.

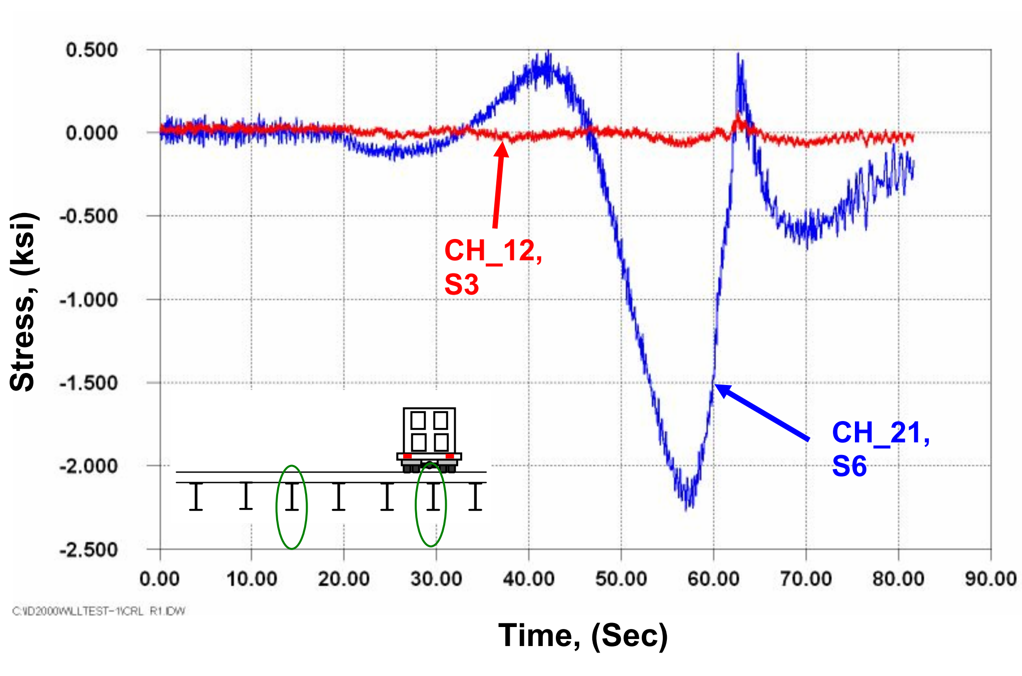


Figure 5.4 – Response of strain gages CH_12 and CH_21 installed on the cross girder web in the web gap area of the cross girder-to-stringer connection of stringer S3 and S6, respectively, as the test truck passed in the right lane in the crawl test (CRL_R1)

Span 12, on web of cross girder at Stringer S3						
Truck in lane	North web face (ksi) (CH_11, S3)			South web face (ksi) (CH_13, S3)		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.1	-0.2	0.3	0.1	-0.5	0.6
Middle	0.1	-0.8	0.9	0.1	-0.3	0.4
Left	0.1	-0.8	0.9	0.2	-0.3	0.5

Span 12, on web of cross girder at Stringer S6						
Truck in lane	North web face (ksi) (CH_20, S6)			South web face (ksi) (CH_22, S6)		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.1	-1.0	1.1	--	--	--
Middle	0.0	-0.3	0.3	--	--	--
Left	0.3	-0.1	0.4	--	--	--

Note:
"--" indicates significant noise in the data

Span 12, on web of cross girder at Stringer S3						
Truck in lane	North web face (ksi) (CH_12, S3)			South web face (ksi) (CH_14, S3)		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.1	-0.1	0.2	0.1	-0.3	0.4
Middle	0.1	-0.5	0.6	0.1	-0.8	0.9
Left	0.1	-0.5	0.6	0.1	-0.7	0.8

Span 12, on web of cross girder at Stringer S6						
Truck in lane	North web face (ksi) (CH_21, S6)			South web face (ksi) (CH_23, S6)		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.4	-2.3	2.7	0.1	-0.8	0.9
Middle	0.9	-0.5	1.4	0.1	-0.6	0.7
Left	0.9	-0.5	1.4	0.2	-0.4	0.6

Table 5.4 – Summary of peak measured stresses, in the web gap area on the web of the cross girder at interior stringers S3 and S6 for the various truck test position in the first crawl tests CRL_R1, CRL_M1, and CRL_L1

5.6 Stresses in the Web Gap of the Cross Girder at the East Fascia Stringer

As discussed earlier, strip gages CH_1 through CH_5 were installed on the web of the cross girder adjacent to the cross girder-to-east fascia connection to measure the stress gradient and assess the potential for the detail to develop cracks in the cross girder web, similar to those developed in the cross girder web at the west fascia connection. The vertical weld attaching the connection plate to the cross girder web was full depth.

Figure 5.5 shows the response of the gages to the passing of the test truck in the left lane in the controlled load test (CRL_L1). As shown in the figure, stress gradient was measured at the detail with strain gage CH_1 measuring the largest peak compressive stresses and strain gage CH_5 measuring the highest peak tensile stresses. It is important to note that the stress range of the two gages were equivalent. A summary of the maximum stress, minimum stress, and stress range values experienced by the gages in the first crawl tests is presented in Table 5.5. The table shows low stresses measured by the gages. All stress ranges were very low, suggesting that trucks with similar or lighter weight will not cause fatigue cracking at the cross girder connection detail at the east fascia.

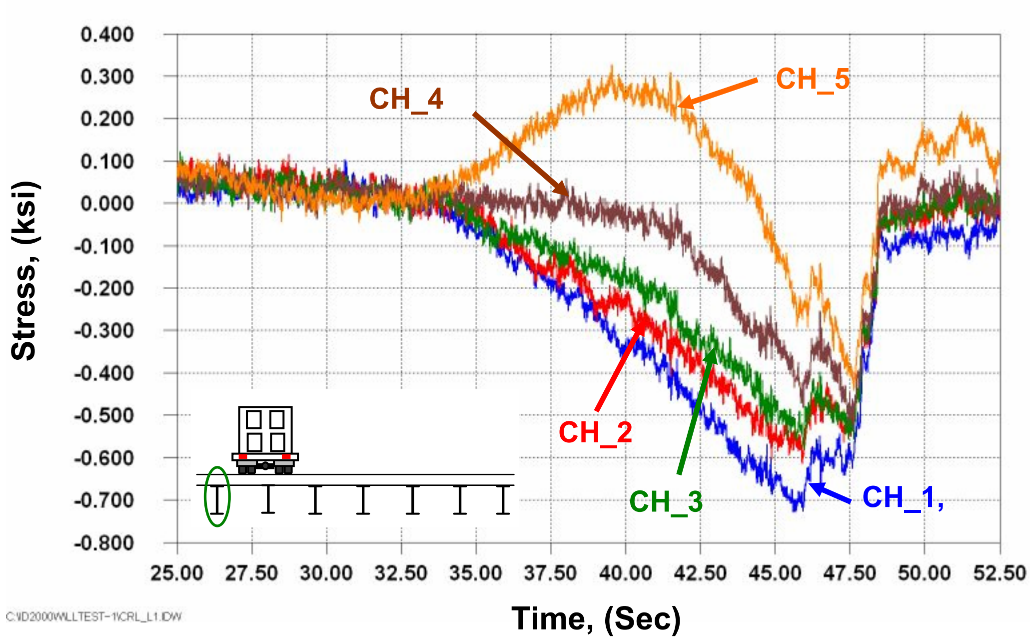


Figure 5.5 – Response of strain gages CH_1 through CH_5 installed on the web of the cross girder adjacent to the web gap area of zero inches at the east fascia to cross girder connection as the test truck passed in the left lane in the crawl test (CRL_L1)

Span 12, on web of cross girder at east fascia						
Truck in lane	North web face (ksi) (CH_1, S1)			North web face (ksi) (CH_2, S1)		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.0	-0.1	0.1	0.0	-0.1	0.1
Middle	0.1	-0.3	0.4	0.1	-0.4	0.5
Left	0.1	-0.7	0.8	0.1	-0.6	0.7

Span 12, on web of cross girder at east fascia						
Truck in lane	North web face (ksi) (CH_3, S1)			North web face (ksi) (CH_4, S1)		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.1	-0.2	0.3	0.1	-0.3	0.4
Middle	0.1	-0.3	0.4	0.1	-0.3	0.4
Left	0.1	-0.6	0.7	0.1	-0.6	0.7

Span 12, on web of cross girder at east fascia			
Truck in lane	North web face (ksi) (CH_5, S1)		
	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.2	-0.4	0.6
Middle	0.2	-0.3	0.5
Left	0.3	-0.4	0.7

Table 5.5 – Summary of peak measured stresses, in the web gap area on the web of the cross girder at the east fascia for the various truck test position in the first crawl tests CRL_R1, CRL_M1, and CRL_L1

5.7 Stresses on Cross Girder Web near Existing Cracks at the Cross Girder-to-West Fascia Connection

As previously mentioned, strain gages CH_28 and CH_29 were installed vertically on the south and north face, respectively, of the cross girder web near the existing longitudinal crack, while strain gages CH_30 and CH_31 were installed horizontally on the south and north face, respectively, of the cross girder web near the vertical end of the existing smiley face crack.

Figure 5.6 shows the response of strain gages CH_28 and CH_29 as the test truck passed over the span in the right lane in the crawl test CRL_R1. The response in both gages is similar, which indicates that there is little out-of-plane distortion of the web. The response in strain gages CH_30 and CH_31, however, is similar in magnitude but with opposite signs, implying out-of-plane bending of the web. Figure 5.7 shows the response of strain gages CH_30 and CH_31 as the test truck passed over the span in the right lane in the crawl test CRL_R1. A summary of the maximum stress, minimum stress, and stress range values experienced by the gages in the first crawl tests is presented in Table 5.6.

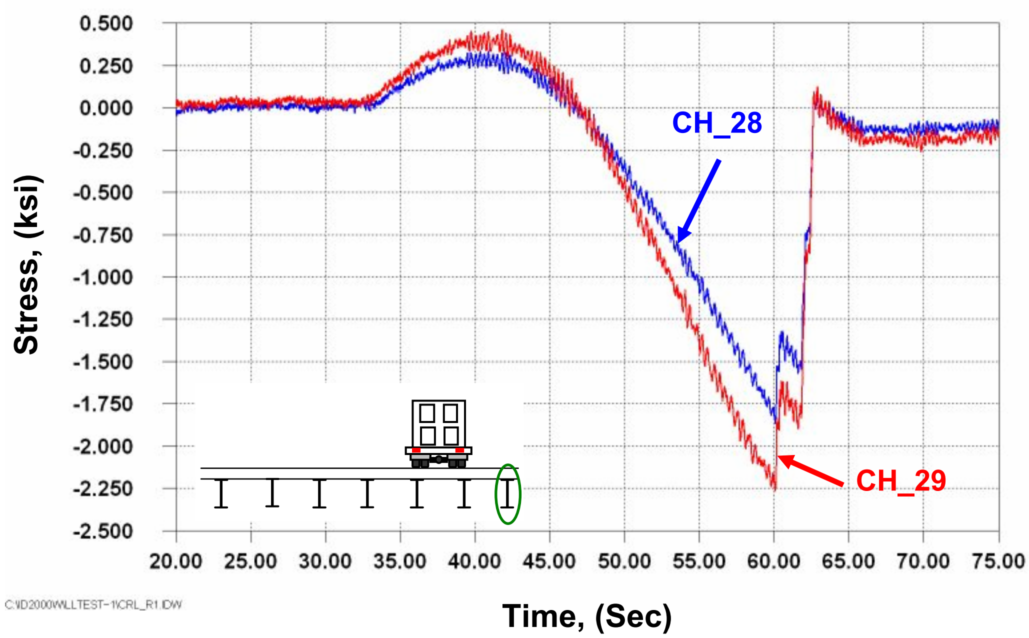


Figure 5.6 – Response of strain gages CH_28 and CH_29 installed transversely on the south and north face, respectively, of the cross girder at 3 inches away from the existing longitudinal crack along the toe of the horizontal weld used for attaching the flange and the web of the cross girder as the test truck passed in the right lane in the crawl test (CRL_R1)

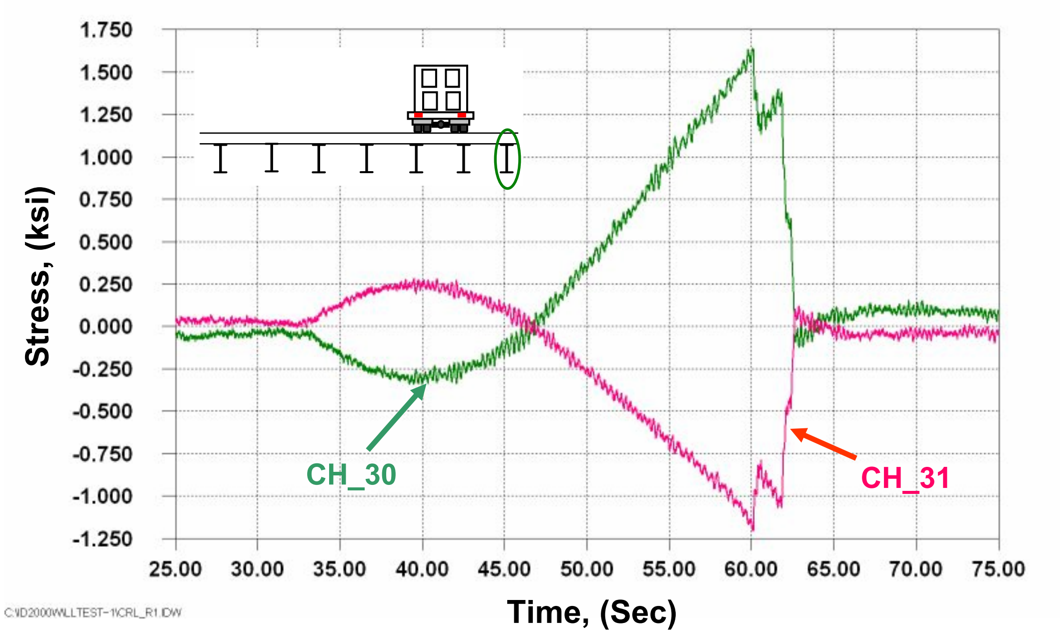


Figure 5.7 – Response of strain gages CH_30 and CH_31 installed longitudinally on the south and north face, respectively, of the cross girder web at 3 inches away from the smiley face crack which originated at the toe of the vertical weld connecting the connection plate to the cross girder web as the test truck passed in the right lane in the crawl test (CRL_R1)

Span 12, on web of cross girder near horizontal crack						
Truck in lane	**Web of cross girder (ksi) (CH_28, south face)**			**Web of cross girder (ksi) (CH_29, north face)**		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	0.3	-1.9	2.2	0.4	-2.3	2.7
Middle	0.2	-1.3	1.5	0.2	-1.5	1.7
Left	0.1	-0.6	0.7	0.1	-0.7	0.8

Span 12, on web of cross girder near smiley face crack						
Truck in lane	**Web of cross girder (ksi) (CH_30, south face)**			**Web of cross girder (ksi) (CH_31, north face)**		
	σ_{max}	σ_{min}	$\Delta\sigma$	σ_{max}	σ_{min}	$\Delta\sigma$
Right	1.7	-0.3	2.0	0.3	-1.2	1.5
Middle	1.2	-0.3	1.5	0.2	-0.9	1.1
Left	0.6	-0.1	0.7	0.1	-0.4	0.5

Table 5.6 – Summary of peak measured stresses, in the web of the cross girder at 3 inches away from the existing cracks located at the west fascia to cross girder connection for the various truck test position in the first crawl tests CRL_R1, CRL_M1, and CRL_L1

5.8 Relative Displacement Between Cross Girder Bottom Flange and Bottom Flange of Stringer

LVDT CH_33 was installed to measure the relative displacement between the cross girder bottom flange and the bottom flange of the interior stringer S3. Similarly, LVDT CH_32 and CH_34 were installed to measure the relative displacement between the cross girder and the east and west fascia, respectively. The LVDT's were installed to assess the out-of-plane bending behavior of the cross girder web and to compare between the relative displacement between the cross girder and the stringers at the three different locations.

Figure 5.8 shows the response of strain gages CH_32 and CH_34 as the test truck crossed over the span in the middle lane in the crawl test (CRL_M1). As expected, the out-of-plane displacement measured by LVDT CH_34 is higher than that measured by LVDT CH_32. This is primarily due to the fact that the cracked cross girder web allows west fascia to undergo more out-of-plane displacement due to the existence of cracks in the cross girder web. A summary of the maximum and minimum relative displacement between the cross girder bottom flange and the bottom flange of the fascia and interior stringers in the first crawl tests is presented in Table 5.7.

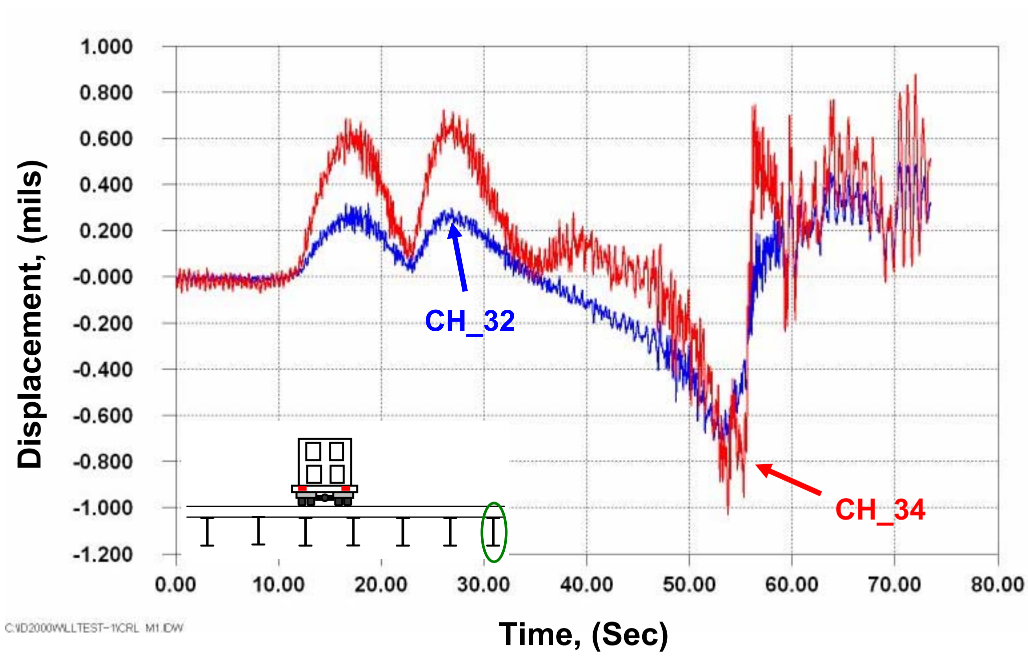


Figure 5.8 – Response of LVDT's CH_32 and CH_34 installed to measure the relative displacement between the cross girder and the east and west fascia, respectively as the test truck passed in the middle lane in the crawl test (CRLM1)

Span 12, relative displacement between cross girder and east and west fascia				
Truck in lane	Cross girder & east fascia flange (inches) (CH_32, S1)		Cross girder & west fascia flange (inches) (CH_34, S7)	
	δ_{max}	δ_{min}	δ_{max}	δ_{min}
Right	0.0005	-0.0014	0.0024	-0.0004
Middle	0.0003	-0.0007	0.0007	-0.001
Left	0.0017	-0.0003	0.001	-0.0026

Span 12, relative displacement between cross girder and interior stringer		
Truck in lane	Cross girder & interior stringer flange (inches) (CH_33, S3)	
	δ_{max}	δ_{min}
Right	0.002	-0.0013
Middle	0.0003	-0.0003
Left	0.0015	-0.0002

Table 5.7 – Summary of peak measured relative displacement between the cross girder bottom flange and the bottom flange of the fascia and interior stringers for the various truck test position in the first crawl tests CRL_R1, CRL_M1, and CRL_L1

5.9 Dynamic response

To assess the dynamic amplification of stresses at the instrumented details, three dynamic tests were conducted using the test truck in different lane positions for each test (i.e. test truck traveling in the right lane, middle lane, and left lane). The truck was travailing with speed of 60 mph in each test. Vibration due to the crossing of the test truck under high speed was observed at some of the instrumented locations. The dynamic response of strain gage CH_27 installed on the bottom flange of the west fascia near midspan is shown in Figure 5.9. A summary of the peak tension and compression stresses for both the crawl tests (CRL_R1) and the dynamic tests (DYN_R1) is shown in Table 5.8.

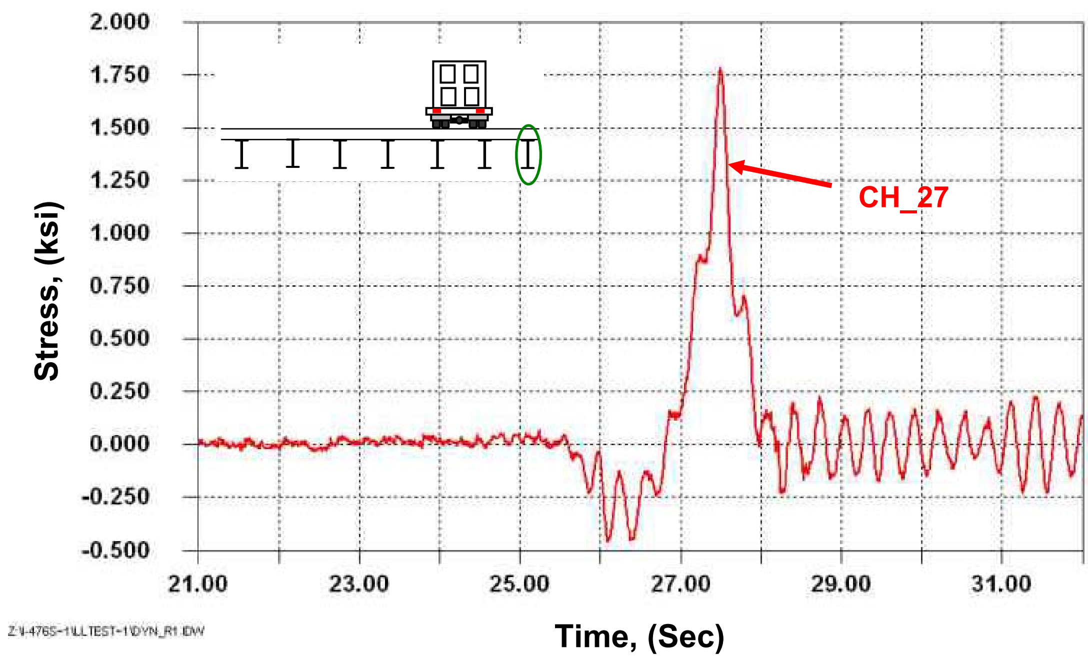


Figure 5.9 – Response of strain gage CH_27 installed on the bottom flange of stringer S6 near midspan of Span 12 at a distance of approximately 55'-4 1/2" north of Pier 11 as the test truck passed in the left lane in the crawl test (CRL_L2)

	Channel No.	Crawl Test (CRL_R1)		Dynamic Test (DYN_R1)		(DYN_R1/CRL_R1)	
		Tens. (ksi)	Compr. (ksi)	Tens. (ksi)	Compr. (ksi)	Tens.	Compr.
Flanges of Stringers Near Cross Girder-to-Stringer Connection	CH_7	0.1	-0.1	0.1	-0.1	1	1
	CH_6	0.3	-0.1	0.3	-0.1	1	1
	CH_16	0.1	0.0	0.0	0.0	0	--
	CH_15	0.1	0.0	0.0	0.0	0	--
	CH_25	0.0	0.0	0.0	0.0	--	--
	CH_24	0.0	0.0	0.0	0.0	--	--
Flanges of Stringers Near Midspan	CH_9	0.1	-0.1	0.3	-0.3	*	*
	CH_8	0.0	0.0	0.0	0.0	--	--
	CH_18	0.6	-0.2	0.7	-0.3	1.17	--
	CH_17	0.0	0.0	0.0	0.0	--	--
	CH_27	1.5	-0.5	1.8	-0.5	1.2	1.0
	CH_26	0.0	0.0	0.0	0.0	--	--
Leg of Angle	CH_10	0.5	-0.2	0.6	-0.6	1.2	*
	CH_19	0.1	-0.7	0.9	-1.0	*	1.43
Web Gap of Cross Girder at Interior Stringers	CH_11	0.1	-0.2	0.3	-0.2	*	1
	CH_13	0.1	-0.5	0.2	-0.5	2	1
	CH_20	0.1	-1.0	0.3	-1.1	*	1.1
	CH_12	0.1	-0.1	0.5	-0.4	*	*
	CH_14	0.1	-0.3	0.6	-0.7	*	2.33
	CH_21	0.4	-2.3	0.7	-2.7	1.75	1.17
	CH_23	0.1	-0.8	0.3	-1.1	*	1.38
Web Gap of Cross Girder at East Fascia	CH_1	0.1	-0.2	0.1	-0.3	1	1.5
	CH_2	0.1	-0.5	0.1	-0.2	1	0.4
	CH_3	0.1	-1.0	0.1	-0.2	1	0.2
	CH_4	0.1	-0.1	0.1	-0.3	1	*
	CH_5	0.1	-0.3	0.2	-0.5	2	1.67
Web Gap of Cross Girder at East Fascia	CH_28	0.3	-1.9	0.5	-2.0	1.67	1.05
	CH_29	0.4	-2.3	0.7	-2.5	1.75	1.09
	CH_30	1.7	-0.3	1.9	-0.5	1.12	1.67
	CH_31	0.30	-1.2	0.4	-1.4	1.33	1.17

Note:
*Dynamic factor is not meaningful because of the low magnitude of stresses

Table 5.8 – Summary of peak tension stress and compression stress for the crawl test (CRL_R1) and the dynamic tests (DYN_R1). Also shown are the stress ratios = (DYN_R1/CRL_R1)

6.0 Short-term Monitoring

All 31 strain gages were chosen for short-term monitoring. Monitoring of the gages was conducted from February 10, 2006 through February 27, 2006, for a period of approximately 18 days. Data recording in the gages was triggered when a predefined stress value was measured in strain gages CH_27, CH_18, and CH_9. Strain gage CH_27 was used for triggering data recording as a result of heavy vehicle traveling in the right lane, strain gage CH_18 was used for triggering data recording as a result of heavy vehicle traveling in the middle lane, and strain gage CH_9 was used for triggering data recording as a result of heavy vehicle traveling in the left lane. For every trigger event, eight seconds of data prior to the event and eight seconds after the event were recorded. In addition to the recorded triggered events, stress-range histograms for selected gages were generated by the data logger using the rainflow cycle counting algorithm.

6.1 Results of Short-term Monitoring

The triggered time-history data and the stress-range histogram data collected during the monitoring period represented the magnitude of the stresses caused by the normal daily traffic. As expected, stresses of higher magnitude than produced by the test truck were observed. No estimate of the remaining fatigue life of the instrumented details was conducted based on the data from the short term monitoring. Previous experience shows that a monitoring period of 30 days or longer is needed to produce near accurate stress history of the normal daily traffic experienced by the bridge. Although no remaining fatigue life estimate was conducted for the instrumented web gap details of the cross girder, the data collected during the short term monitoring show that the recorded stress ranges at the details were not high, usually well below the CAFL.

6.2 Stress-Range Histograms

6.2.1 Stresses in the Top and Bottom Flanges of the Stringers

As previously discussed, strain gages were installed on the top and bottom flange of the fascia and interior stringers near the cross girder-to-stringer connection and near midspan. Similar to what is observed in the controlled load tests; low stresses were measured in all gages installed on the top flange of the interior and fascia stringers near midspan. Furthermore, low stresses were measured in all gages installed on the top and bottom flange near the cross girder-to-stringer connection. The maximum stress ranges in the bottom flange of the stringers were recorded by strain gage CH_27 installed on the bottom flange of stringer S6 near midspan to be 4.25 ksi. Figure 6.1 shows a triggered time event recorded by gage CH_27 during the monitoring period. Figure 6.2 shows the stress-range histogram for strain gage CH_27. The inset in the figure is a magnification of the right-most portion of the histogram.

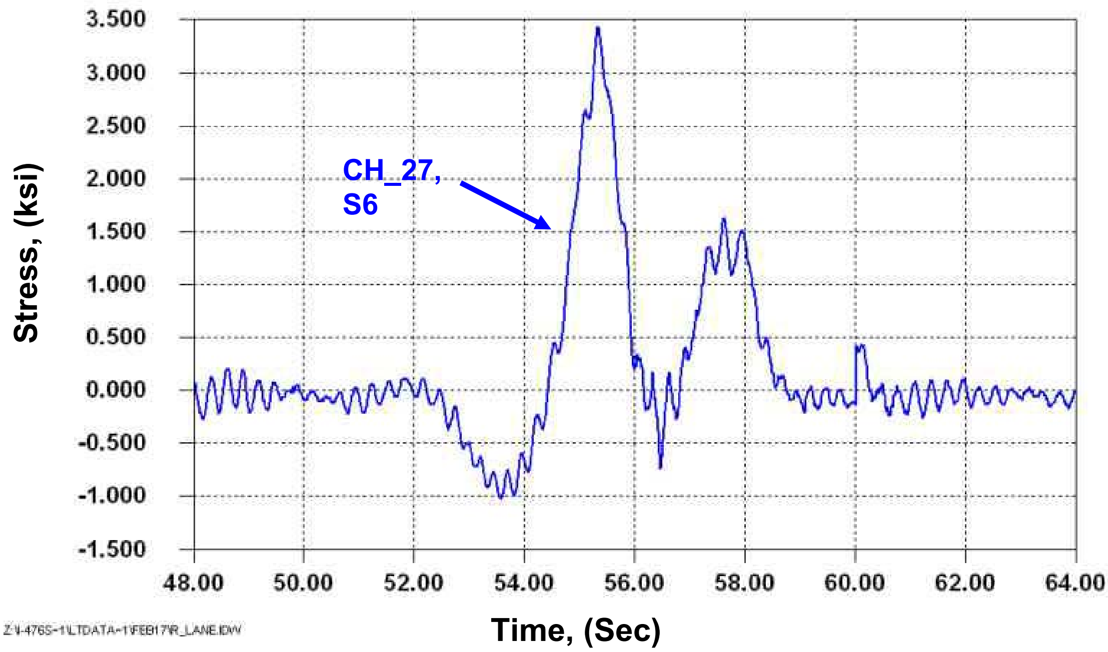


Figure 6.1 - Stress time-history for strain gage CH_27 installed on the bottom flange of stringer S6 near midspan of span 12 during the passage of a vehicle during monitoring

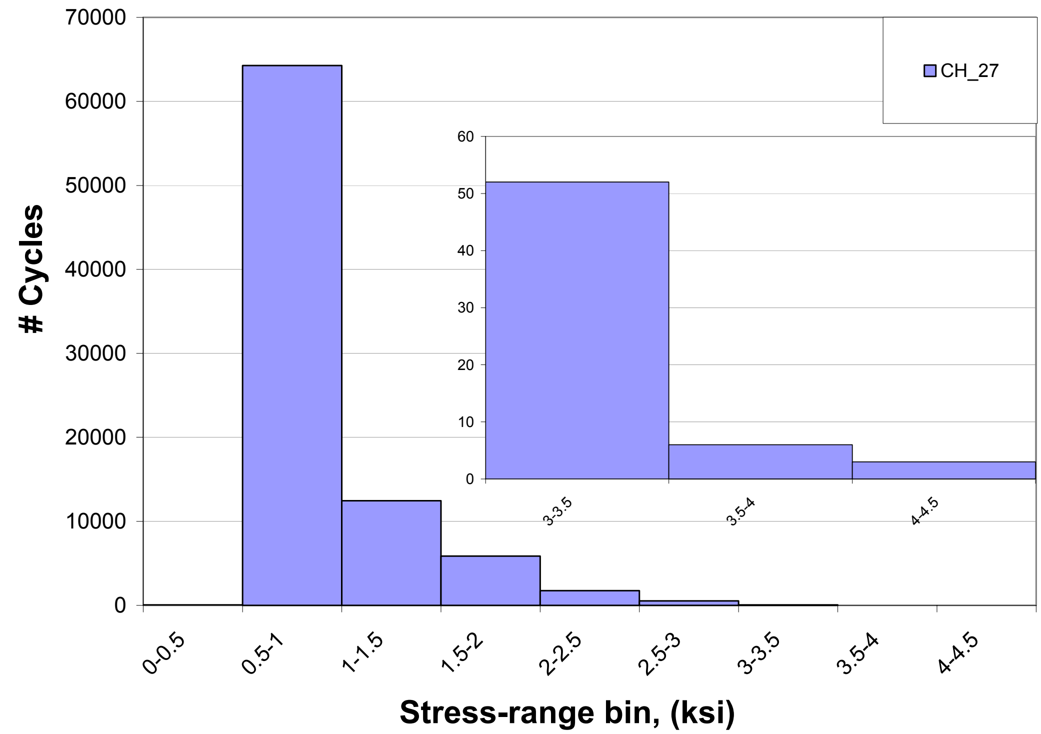


Figure 6.2 – Stress-range histogram for strain gage CH_27 installed on the bottom flange of stringer S6 near midspan of span 12

6.2.2 Stresses on the Leg of the Retrofit Angle at the Fascia Stringers

As stated earlier, strain gages CH_10 and CH_19 were installed on the leg of the retrofit angles bolted to the web of the east and west fascia stringers, respectively to measure the magnitude of stresses transmitted by the fascia stringers to the cross girder through the retrofit angles. Stresses higher than those measured during controlled load tests were recorded by both gages. Figure 6.3 shows the stress-range histogram for strain gages CH_10 and CH_19. The inset in the figure is a magnification of the right-most portion of the histogram. As shown in the figure, the maximum stress range recorded by strain gage CH_19 is higher than the maximum recorded by strain gage CH_10. This was expected since strain gage CH_19 was installed on the retrofit angle of the west fascia located below the right lane, which typically experiences heavy truck traffic than the adjacent lanes.

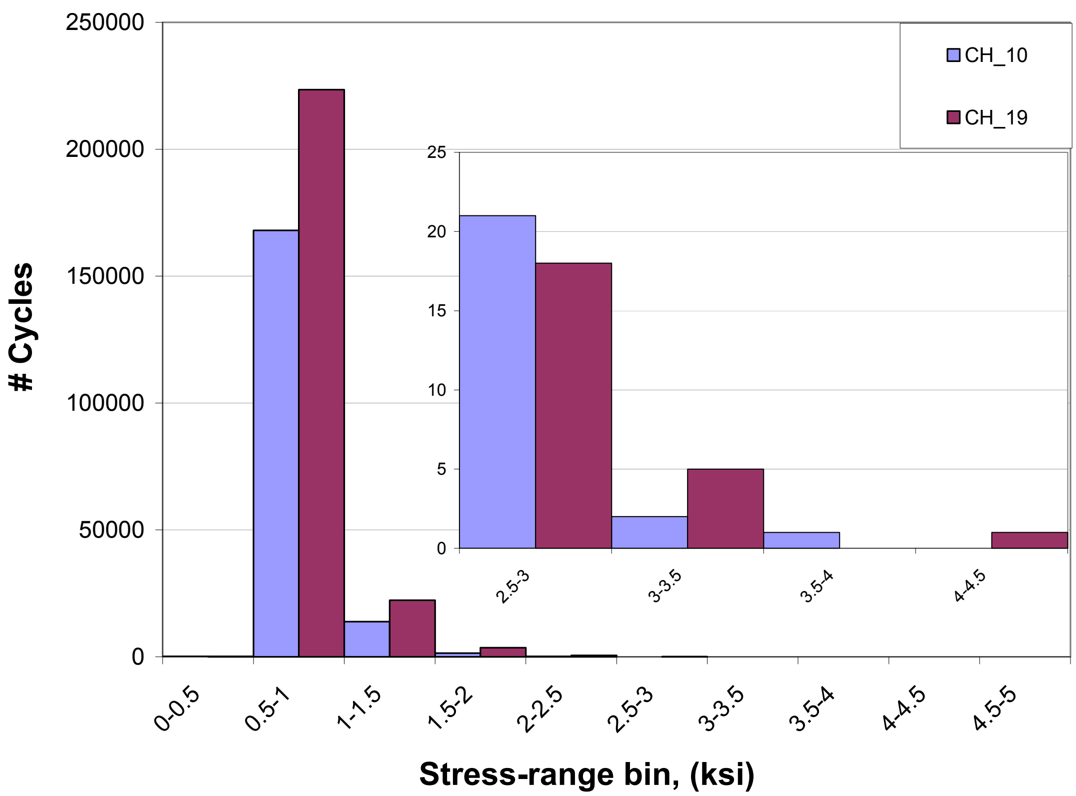


Figure 6.3 – Stress-range histogram for strain gages CH_10 and CH_19 installed on the leg of the retrofit angles bolted to the web of the east and west fascia, respectively

6.2.3 Stresses in the Web Gap of the Cross Girder at Interior Stringers

As previously mentioned in Section 4.2.2, strain gages were installed in the web gap of the cross girder on both faces of the web at interior stringers S3 and S6. At interior stringer S3, strain gage CH_14 was installed vertically in the web gap on the south face of the gross girder web and fit tight against the horizontal weld of the cross girder flange and vertical weld of the transverse stiffener. Strain gage CH_13 was installed directly above strain gage CH_14. Strain gages CH_12 and CH_11 were installed on the north face of the web by projecting strain gages CH_14 and CH_13, respectively. Similarly, at interior stringer S6, strain gage CH_23 was installed similar to strain gage CH_14, strain gage CH_22 was installed similar to strain gage CH_13, strain gage CH_21 was installed similar to strain gage CH_12, and strain gage CH_20 was installed similar to strain gage CH_11. Stresses measured at the web gap detail at interior stringer S6 were higher than those measured at interior stringer S3 and was recorded to be 9.3 ksi, 6.7 ksi, 10.7 ksi, and 6.8 ksi in strain gages CH_20, CH_21, CH_22, and CH_23, respectively. Figure 6.4 shows the stress-range histogram for strain gages CH_11 and CH_13 installed on the north and south face of the cross girder web in the web gap area at interior stringer S3. The maximum average stress range recorded by both gages was one cycle of 2.25 ksi.

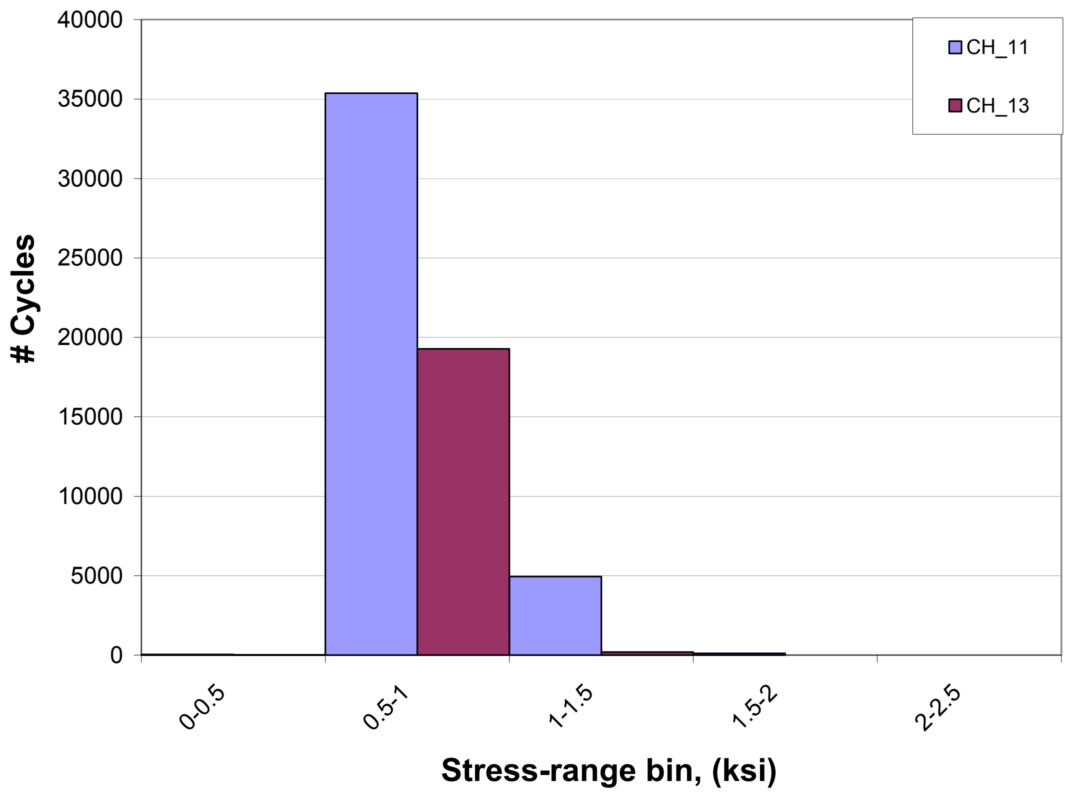


Figure 6.4 – Stress-range histogram for strain gages CH_11 and CH_13 installed on the north and south face of the cross girder web in the web gap area at interior stringer S3

6.2.4 Stresses in Web Gap of Cross Girder at East Fascia

Strain gages CH_1 through CH_5 were installed on the web of the cross girder adjacent to the vertical weld in the web gap at the cross girder-to-east fascia stringer connection. The maximum stress range recorded by the gages was 1.6 ksi and was measured by strain gage CH_1. Figure 6.5 shows the time-history response of strain gages CH_1 through CH_5 during a trigger event.

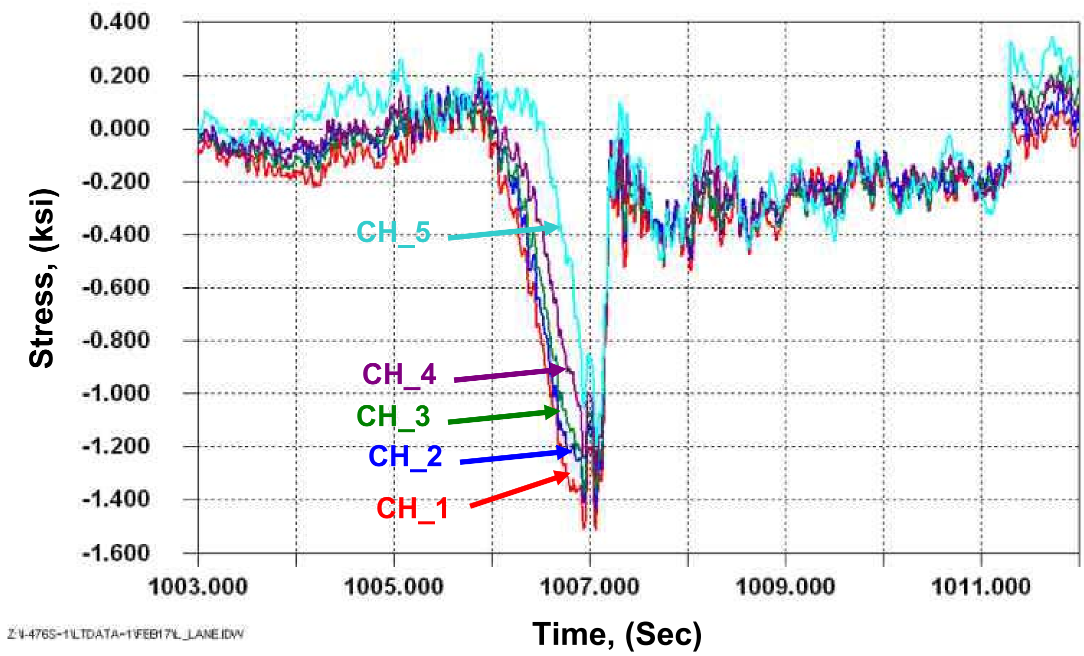


Figure 6.5 - Stress time-history for strain gage CH_1 through CH_5 installed on the web of the cross girder adjacent to the web gap at the cross girder-to-east fascia stringer connection during the passage of a vehicle during monitoring

6.2.5 Stresses on Cross Girder Web near Existing Cracks at the Cross Girder-to-West Fascia Connection

As mentioned in Section 4.2.4, strain gages were installed near the existing cracks located on the cross girder web at the west fascia. Specifically, strain gages CH_28 and CH_29 were installed vertically on the south and north face, respectively, of the cross girder web near the existing longitudinal crack, while strain gages CH_30 and CH_31 were installed horizontally on the south and north face, respectively, of the cross girder web near the existing smiley face crack. The maximum stress range measured by the gages during monitoring was 4.7 ksi in strain gage CH_28, 7 ksi in strain gage CH_27, 7.9 ksi in strain gage CH_30, and 6.9 ksi in strain gage CH_31. Figure 6.6 shows the time-history response of strain gages CH_28 and CH_29 during a trigger event.

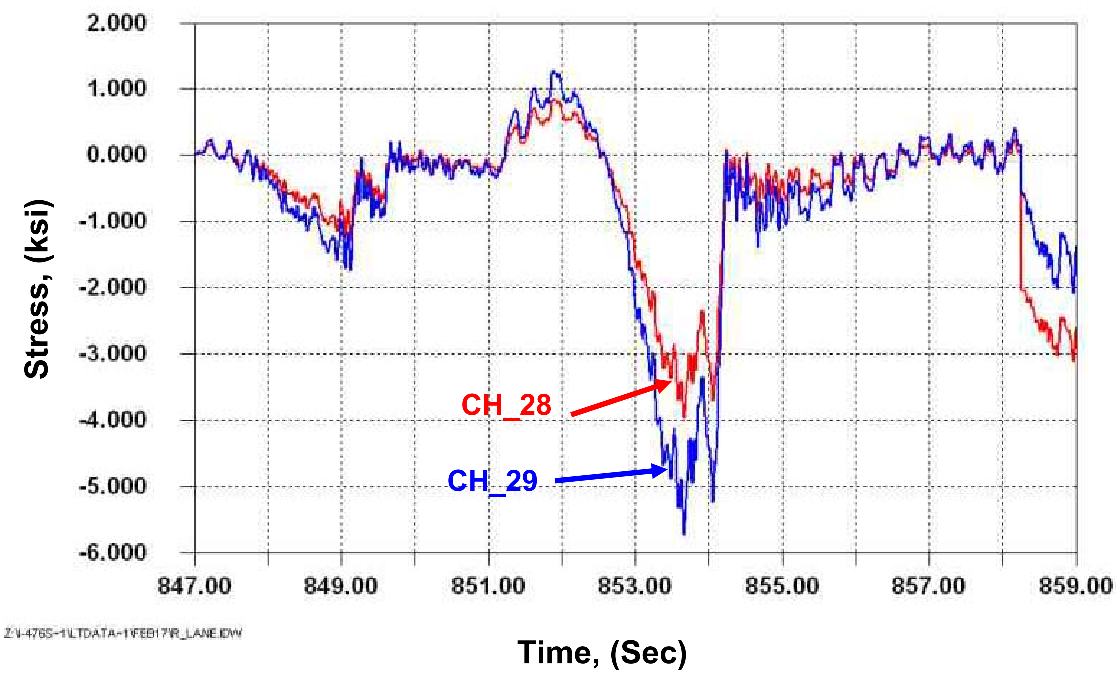


Figure 6.6 - Stress time-history for strain gages CH_28 and CH_29 installed vertically on the south and north face, respectively, of the cross girder web near the existing longitudinal crack during the passage of a vehicle during monitoring

7.0 Summary

The following section provides a summary of the project and the results of the controlled load testing and short-term monitoring conducted on the Harbor Memorial Bridge in Montgomery County, PA.

Instrumentation Plan

1. Instrumentation was installed in Span 12 of the south bound bridge at key locations to determine the overall response of the bridge and to quantify the stress-range histograms at critical details.

2. Instrumentation included strain gages at the web gap details on the web of the cross girder at Pier 11, strain gages on the top and bottom flange of the stringers, strain gages on the retrofit angle bolted to the east and west fascia stringers, and displacement sensors at cross girder web gap.

Controlled Load Testing

1. The response was typical of a two-span continuous bridge.

2. Low response for the strain gages installed on the top flange of the stringers, indicating composite action between the deck and the stringer of the instrumented span.

3. Low response for the strain gages installed on the top and bottom flange of the stringers near the cross girder-to-stringer connection at Pier 11, indicating that very low magnitude of flexural moment is transmitted between the stringers and the cross girder.

4. In all crawl tests, the retrofit angle at the west fascia stringer had higher stresses than the retrofit angle of the east fascia stringer.

5. Stresses measured by strain gage CH_21 installed at the web gap detail of interior stringer S6 was higher than those measured by strain gage CH_12 installed at similar location at interior stringer S3.

6. Low response was measured by the strip gages installed at the web gap detail of the east fascia stringer.

7. The out-of-plane displacement measured by LVDT CH_34 installed at the west fascia was higher than that measured by LVDT CH_32 installed at the east fascia.

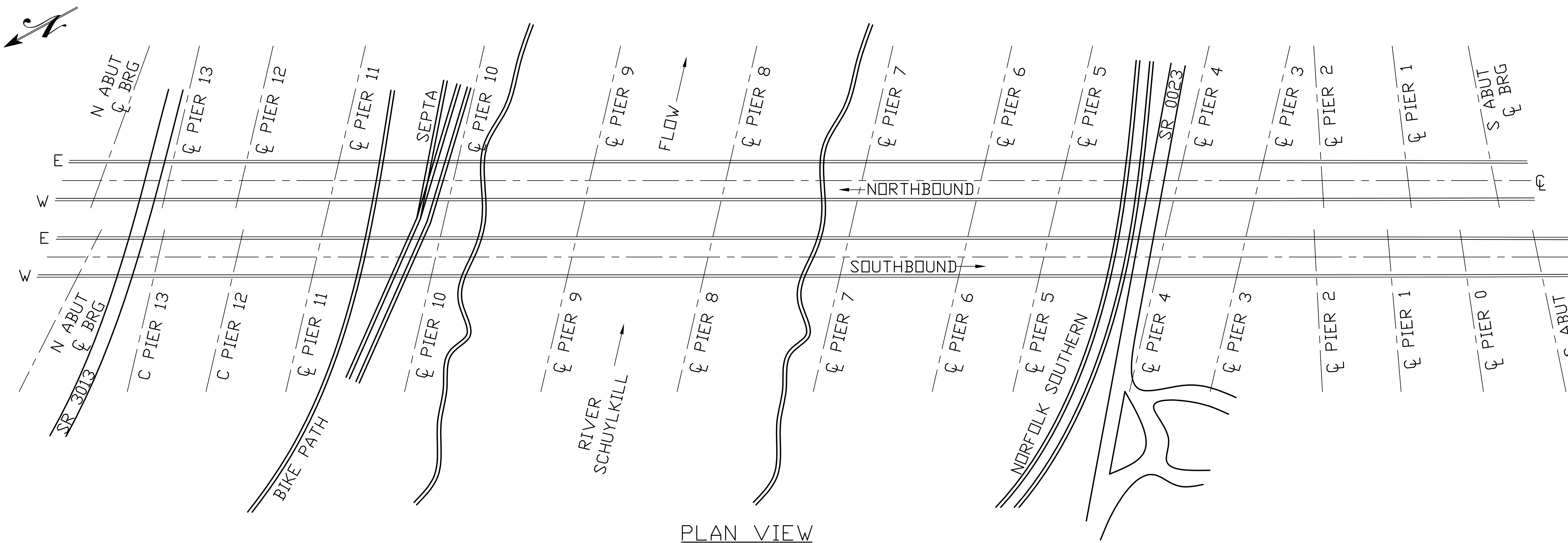
Short-Term Monitoring

1. Stresses of higher magnitude than produced by the test truck were observed.

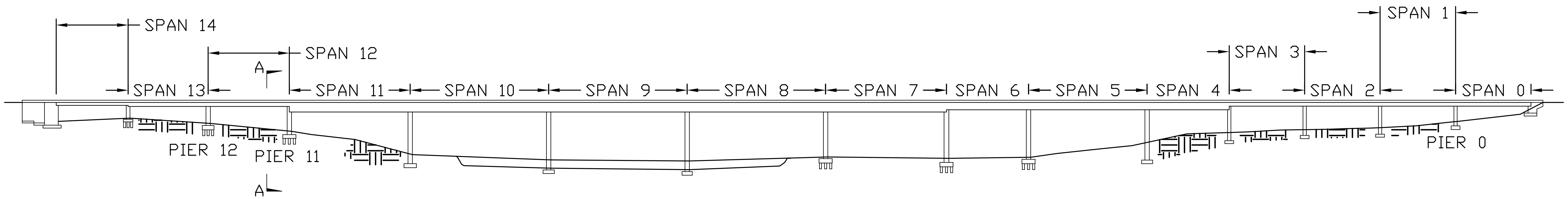
2. Although no estimate of the remaining fatigue life of the instrumented web gap details was conducted, the data collected during the short-term monitoring show that the recorded stress ranges at the detail were not high and usually well below the CAFL of the detail.

Appendix A

Instrumentation Plans



PLAN VIEW
SCALE: 1/160"=1'-0"



SOUTH BOUND WEST ELEVATION
SCALE: 1/160"=1'-0"

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Bethlehem, PA 18015
610-758-3535 FAX 610-758-6842

PROJECT:

I-476 SOUTHBOUND BRIDGE OVER THE SCHUYLKILL RIVER

SHEET NOTES:

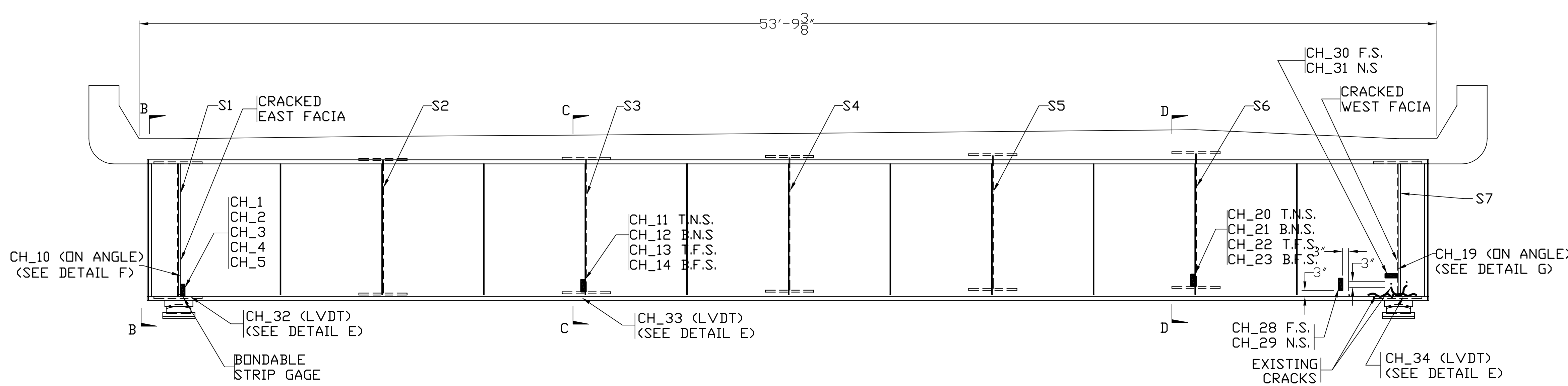
NO.	DESCRIPTION	DATE	BY
1	INITIAL SUBMITTAL	3/15/06	HNM

DESIGNED BY:	HNM, BTY
DRAWN BY:	SEM
CHECKED BY:	HMB, BTY
SCALE:	AS SHOWN
DATE:	3/15/06
PROJECT NO.:	526704

SHEET TITLE:

INSTRUMENTATION PLANS

SHEET NO.:



SECTION A-A: ELEVATION OF CROSS GIRDER AT PIER 11 (CG1)
SCALE: 3/16"=1'-0"

NOTE: LVDT ARE RELATIVE DISPLACEMENT BETWEEN CROSS GIRDER FLANGE AND CONNECTION PLATE

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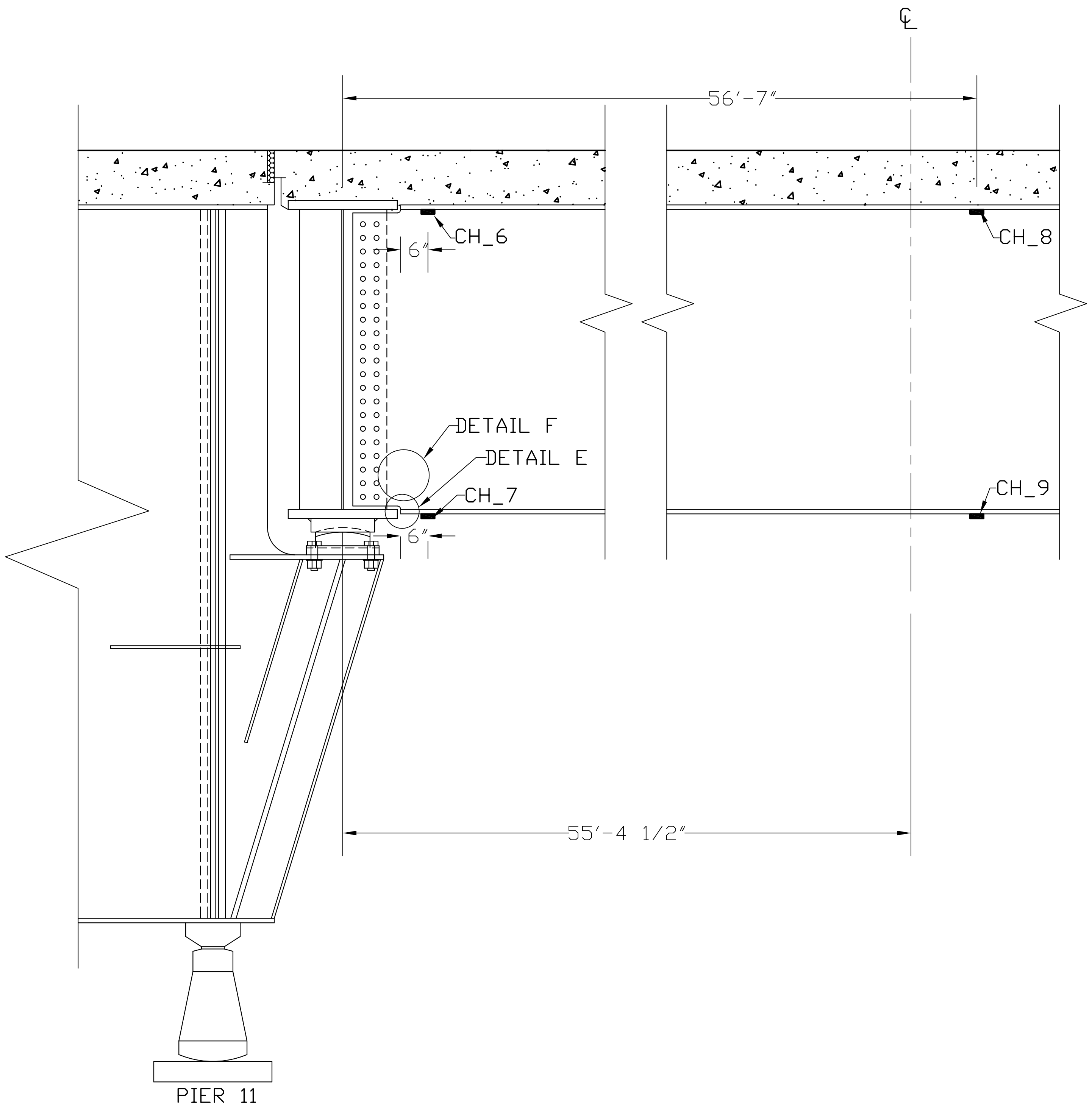
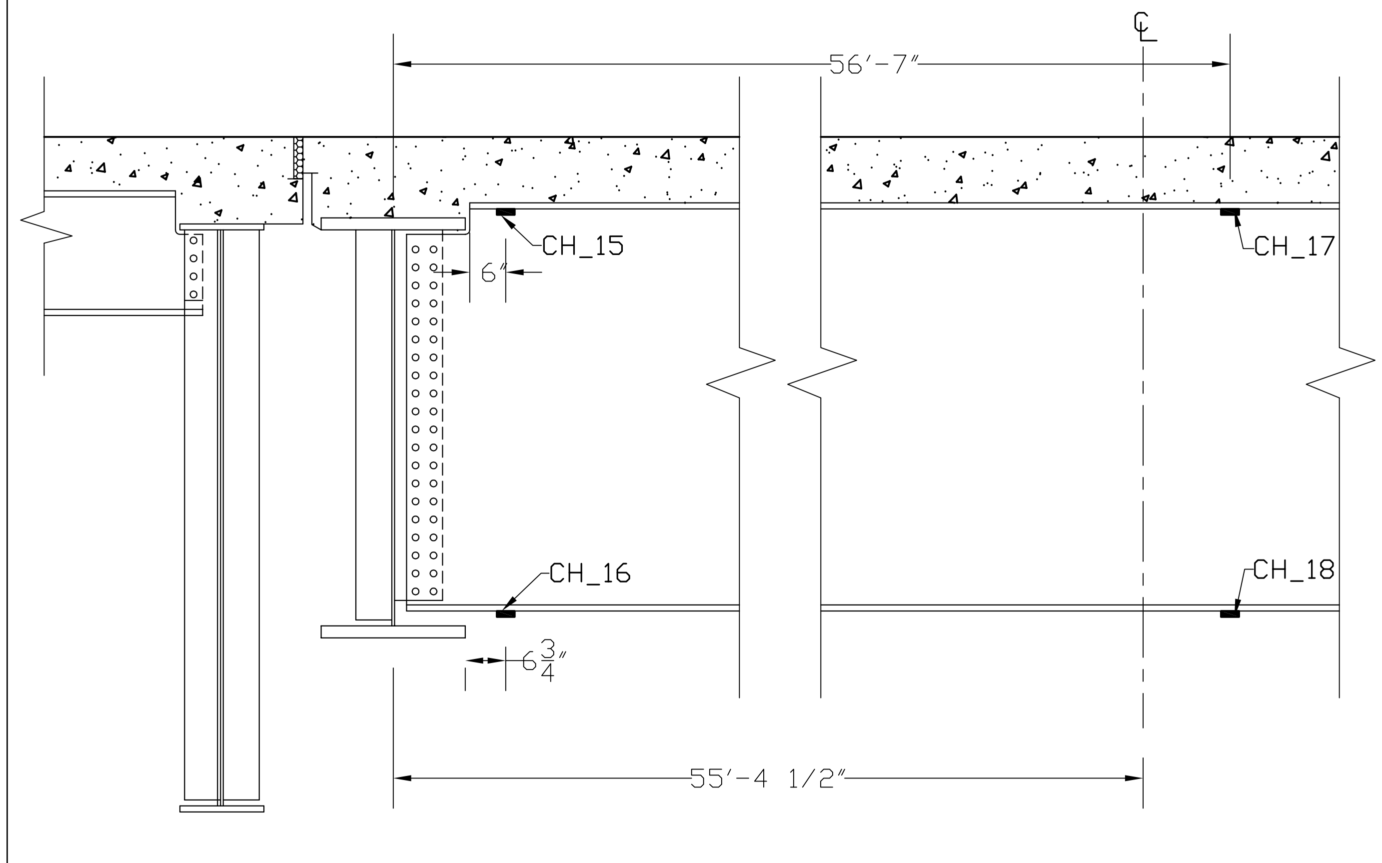
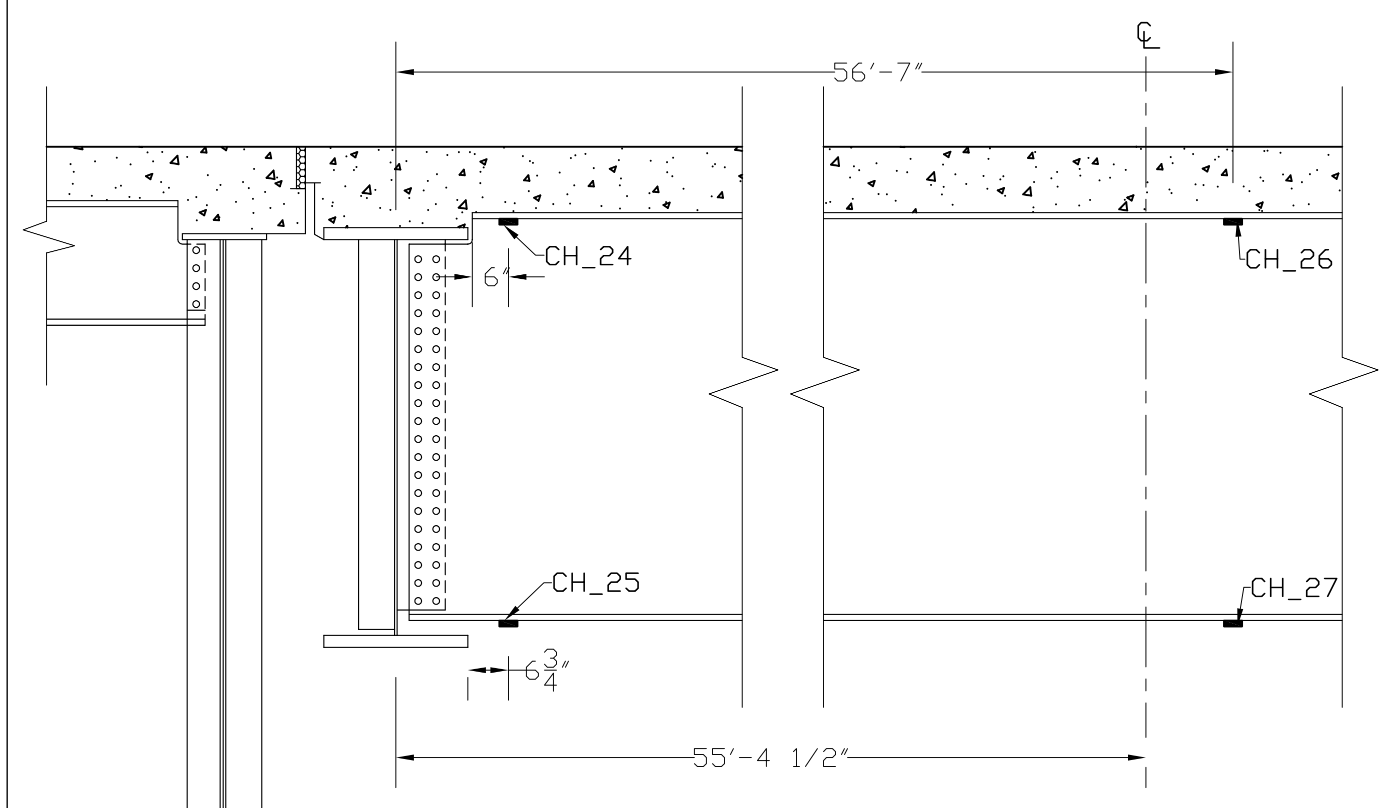


SECTION B-B: EAST FACIA STRINGER
SCALE: 3/8"=1'-0"



SECTION C-C: INTERIOR STRINGER 3
SCALE: 3/8"=1'-0"



SECTION D-D: INTERIOR STRINGER 6
SCALE: 3/8"=1'-0"

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PROJECT NO.:	526704

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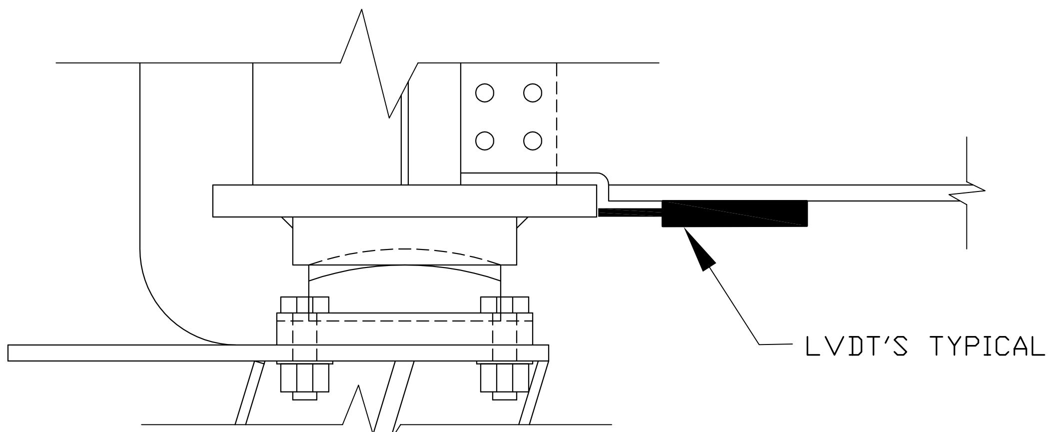
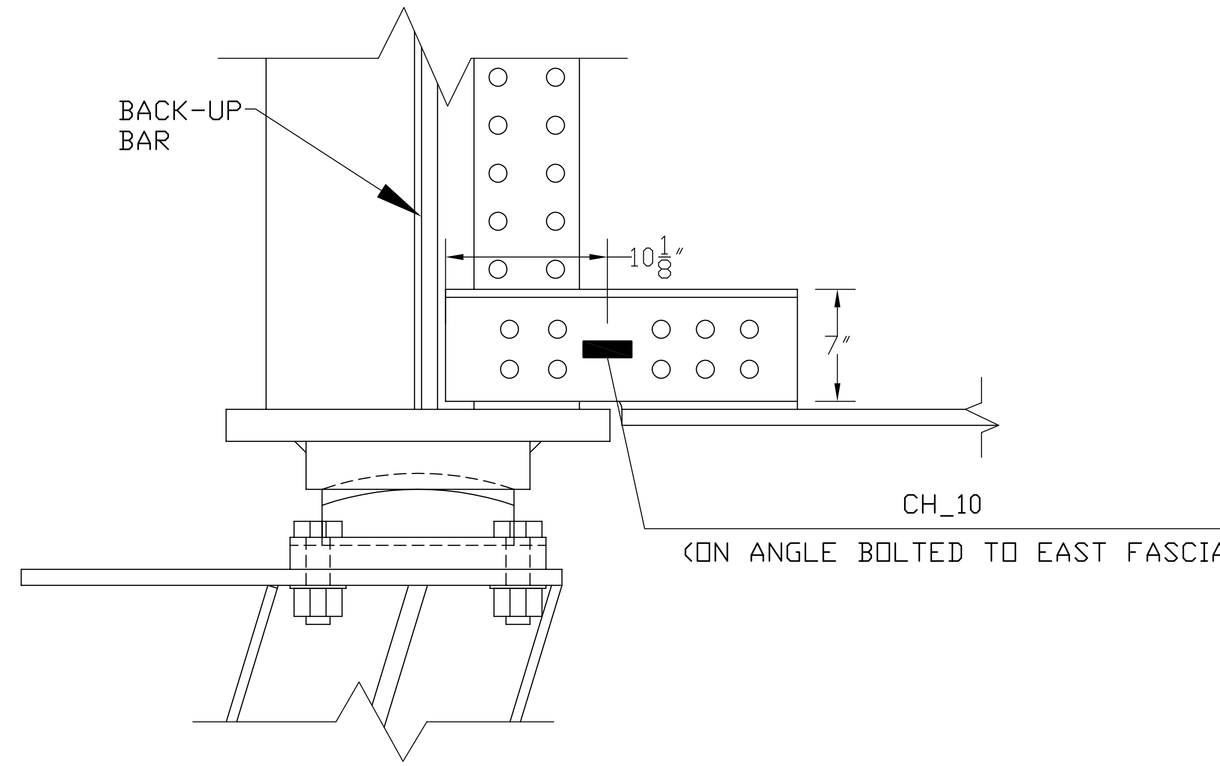
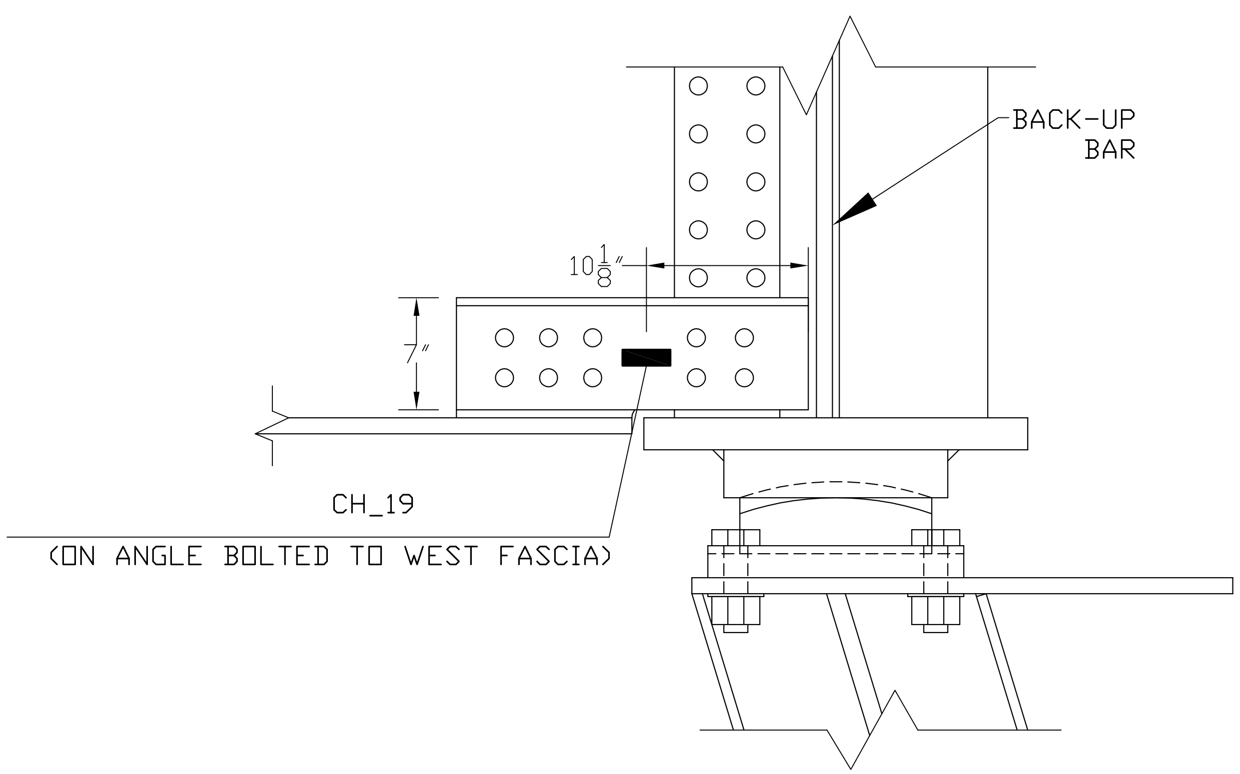
3 OF 4



DETAIL E: CROSS GIRDER FLANGE AND CONNECTION PLATE
SCALE: 1"=1'-0"



DETAIL F: CONNECTION ANGLE ON WEST FACE OF EAST FASCIA
SCALE: 1"=1'-0"



DETAIL G: CONNECTION ANGLE ON EAST FACE OF WEST FASCIA
SCALE: 1"=1'-0"

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