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ABSTRACT

In November 1999, bonded Fiber-Reinforced Polymer (FRP) laminates were used to strengthen a single span, reinforced concrete T-beam bridge in New York State. The laminate system was installed to strengthen the structure in flexure and shear, and to contain observed freeze-thaw cracking. The bridge was then instrumented and load tested before and after installation of the laminates, to evaluate effectiveness of the strengthening FRP system. In November 2001, the load test was repeated to monitor in-service performance of the system. The test results indicated that the quality of bond between the laminates and concrete, and effectiveness of the system have not deteriorated after two years of service. Further inspection using an Infrared thermography camera did not show any significant delamination in the system, in agreement with the test results.

CONTENTS

I. INTRODUCTION

Many transportation agencies have recognized the advantages of FRP materials in bridge retrofit applications. Strength, non-corrosive properties, and ease of application with limited interruption to traffic are some of the materials well recognized advantages (*1-3*). Typically, application of these materials requires preparation of a deteriorated bridge member's surface to receive an epoxy-bonded FRP laminate/plate system. The FRP manufacturer's recommendations, for surface preparation and application of the system, are generally followed. In strengthening applications, where the bond between the FRP laminates and the concrete surface is very crucial, proper surface preparation and application are very important for the long-term success of the retrofit system. Lack of adequate methods to control the quality of an FRP installation, emphasizes the need for Non Destructive Evaluation/Testing (NDE/T) techniques to monitor and assess effectiveness of the bond. Such techniques are also needed to ensure that the laminate bond is maintained during the service life of the retrofit. For detection of localized bond flaws, coin tapping and thermographic imaging are generally used, and for global assessment of bond quality and effectiveness of the FRP retrofit system, load testing is often a more practical choice.

Bridge strengthening using FRP materials is generally less costly than replacement and significantly shortens downtime for rehabilitation, which reduces inconvenience to the traveling public and economic loss to areas served (*2*). In November 1999, FRP laminates were used to improve the load carrying capacity of a T-Beam bridge in Rensselaer County, New York. Using bonded FRP laminates in this project demonstrated the application of the innovative FRP materials for cost-effective rehabilitation of deteriorated reinforced concrete bridges to improve their capacity and extend their service life. Limited experience with FRP materials in bridge applications created a need for in-service monitoring, for any degradation that may affect the materials useful life. This report briefly describes the bridge strengthening and discusses the load test conducted in November 2001, to evaluate in-service performance of the FRP strengthening system after being in service for two years.

A. BACKGROUND AND OBJECTIVES

The bridge was built in 1932, and carries Route 378 over the Wynantskill Creek in the City of South Troy, NY. It is a 12.19-m (42-ft) long, 36.58-m (120-ft) wide reinforced-concrete structure, consisting of 26 simply-supported T-beams, spaced at 1.37 m (4.5 ft) on centers, with an integral concrete deck. A plan view of the bridge is shown in Figure 1 and a typical beam section is depicted in Figure 2. The main reinforcement consist of 8, 32 x 32 mm^2 (1¼ x 1¼ $in.^2$) square steel bars. The bridge carries five lanes of traffic, has an ADT of about 30,000 vehicles, and has been open to traffic without weight-limit restrictions (*2*).

Concerns over section loss of the reinforcing steel to corrosion and overall safety of the structure prompted the bridge strengthening in November 1999 using FRP laminates. The purpose of the strengthening was to improve flexural and shear capacities, and to contain observed freeze-thaw cracking in the bridge beams *(2,3,4)*. The bridge was instrumented and load tested before and after installation of the FRP laminates, to evaluate effectiveness of the strengthening system. Shortly after the testing was conducted, the bridge asphalt wearing surface was removed, a waterproofing membrane installed, and a new asphalt surface was put in place.

FIGURE 1. Plan view of the bridge.

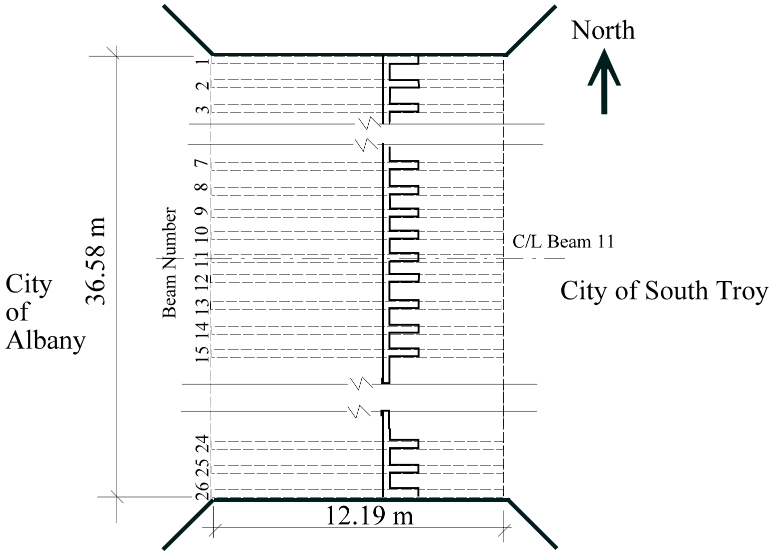
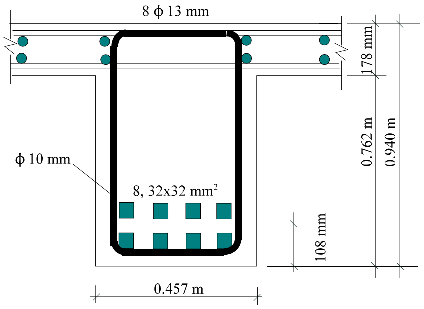


FIGURE 2. A typical beam section.



B. FRP STRENGTHENING SYSTEM

The Replark® laminate system was used in the bridge retrofit design (Figures 3 and 4). The system consists of Replark 30® unidirectional carbon fibers and three types of Epotherm materials (primer, putty, and resin) all manufactured exclusively by Mitsubishi Chemical Corporation of Japan (*5*). The ultimate strength of the laminate system is 3400 MPa (493 ksi), corresponding to a guaranteed ultimate strain of 1.5 percent. Details of the laminate system are shown in Figure 3. In this figure, laminates located at the bottom of the webs and those between beams are oriented parallel to the beams. Those at the flange soffits, spanning between the beams, are oriented at a right angle to the beams. The U-jacket laminates, applied on the bottom and sides of the beams, are oriented parallel to the legs of the U-jackets.

FIGURE 3. Laminate system detail.

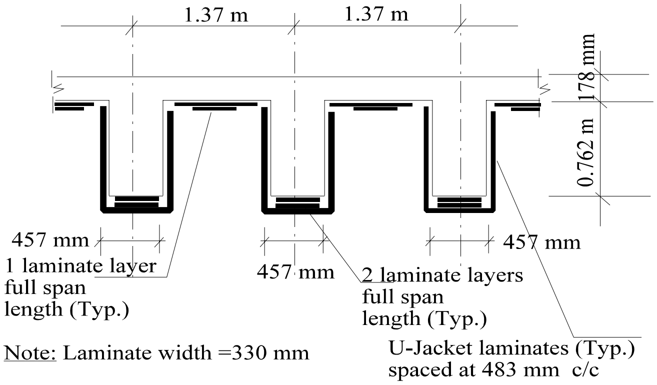


FIGURE 4. Installed laminate system.

C. REPORT ORGANIZATION

This report has 3 additional chapters. The next chapter describes the FRP strengthening system installed in 1999 and the instrumentation used in the before and after installation tests during that year. The chapter also discusses the plan for the 2001 load test, conducted to monitor in service performance of the installed system. The 2001 test results are presented and analyzed in Chapter 3. The analysis includes general flexural behavior of the most stressed beam during the testing, bond between the FRP laminates and concrete, effective flange width, and neutral axis location. Conclusions are summarized in the final chapter of the report.

II. INSTRUMENTATION AND LOAD TEST PLANS

The 1999 instrumentation and loading plans *(2)* were designed to provide data for investigation of 1) the effectiveness of the FRP retrofit system in reducing the steel rebar stresses, 2) the laminate bond to the concrete, and 3) the effect of the retrofit system on transverse load distribution, effective flange width, and neutral axis location.

A. INSTRUMENTATION

Nine beams, four on each side of Beam 11, were instrumented, to provide information on transverse load distribution on the bridge. General purpose 350 Ω, self temperature-compensating, constantan foil strain gages, were mounted directly on the reinforcing steel and FRP laminates. On concrete, 120 Ω, constantan strain gages with large measuring grids were bonded using an epoxy resin. See Figures 5-7 for gages mounted on steel, concrete, and FRP laminates (*2*). All gages were made watertight and protected from the environment for long-term monitoring purposes. System 6000, a general purpose data acquisition system, manufactured by the Measurements Group®, was used for data collection.

FIGURE 5. Strain gages mounted on steel rebars.

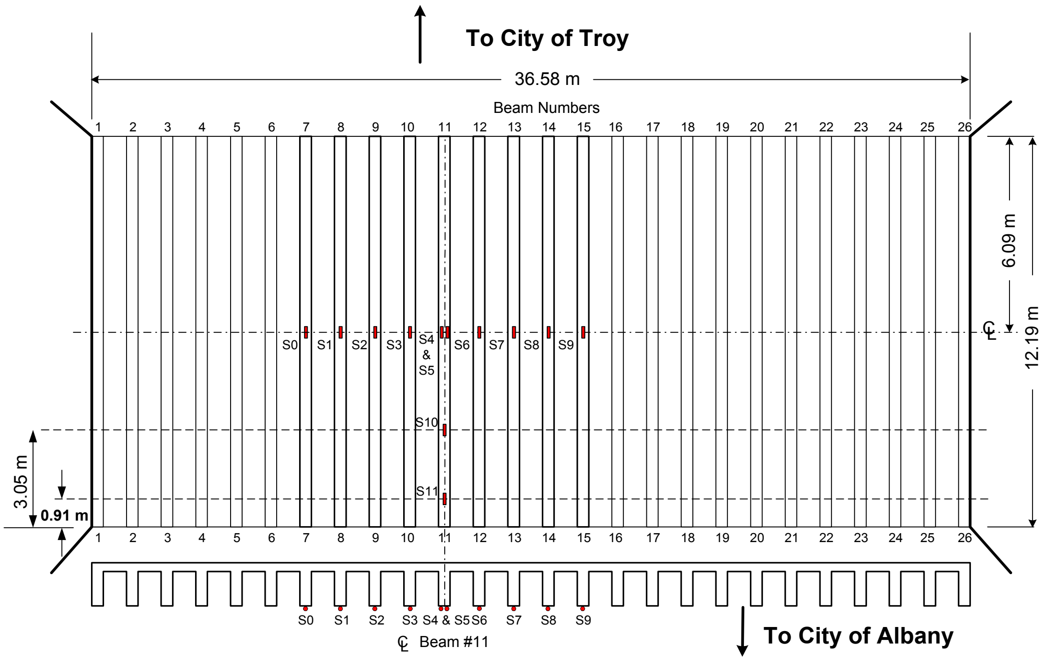
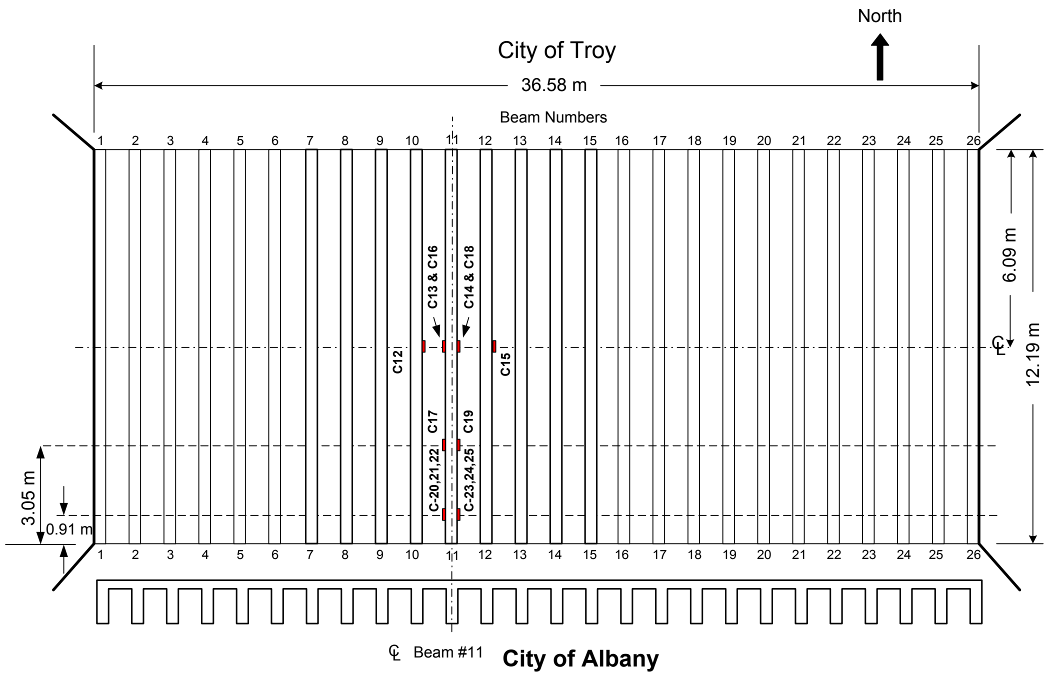
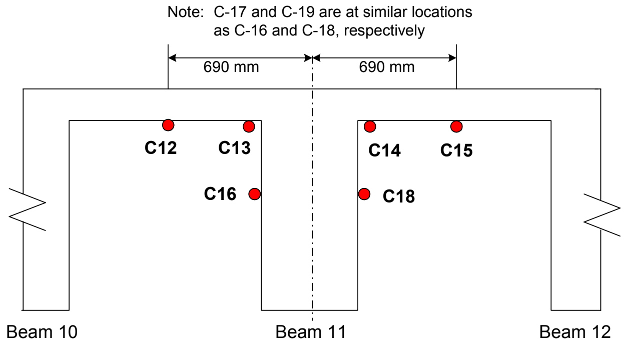
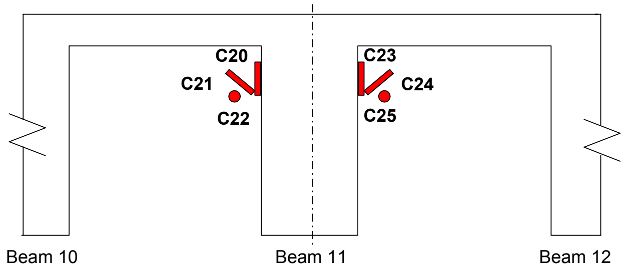


FIGURE 6. Strain gages mounted on concrete.



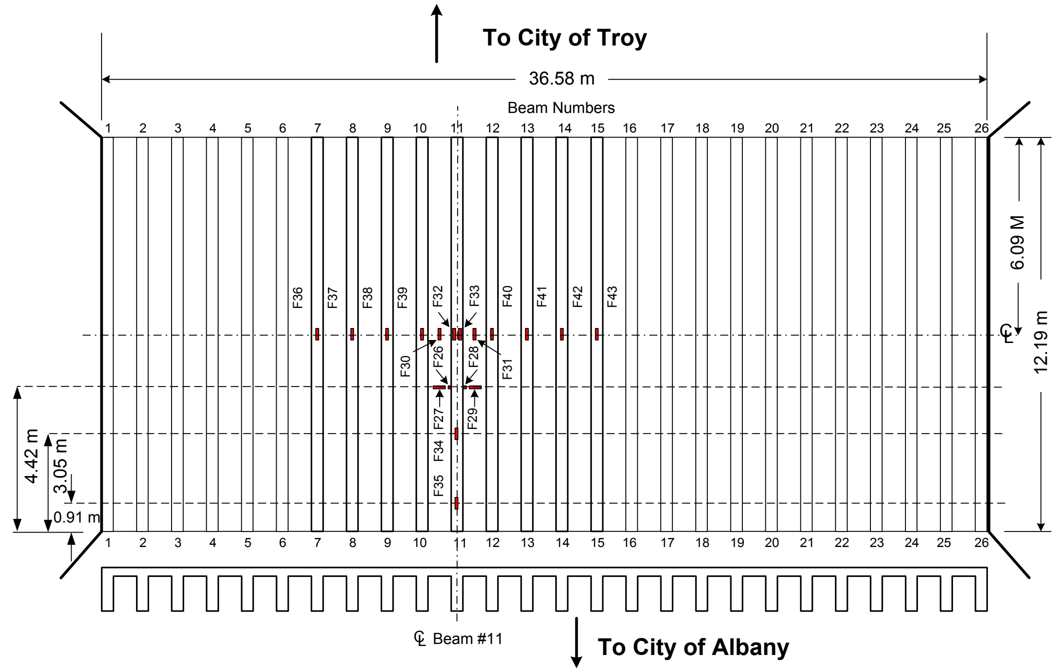


Concrete gages on Beam 11
at midspan

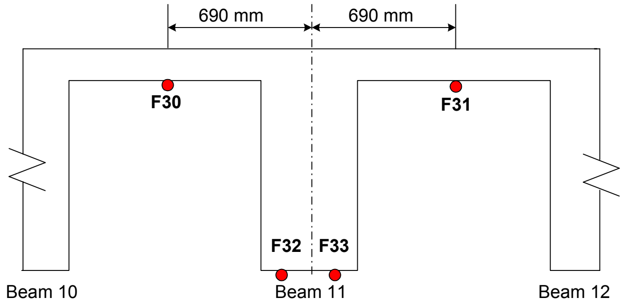


Concrete gages on Beam 11
at 0.91m from abutment

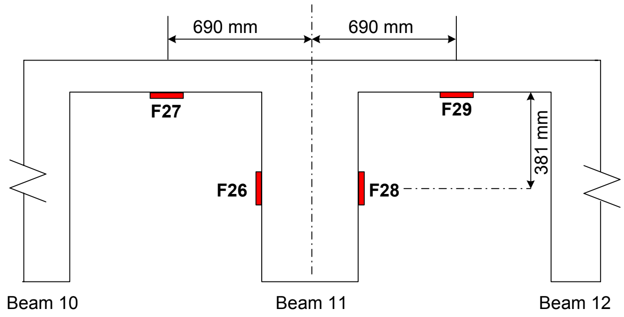
FIGURE 7. Strain gages mounted on FRP laminates.



Note: Gages F-34 and 35 are located at the bottom of beam 11.



FRP laminate gages on Beam 11 at midspan

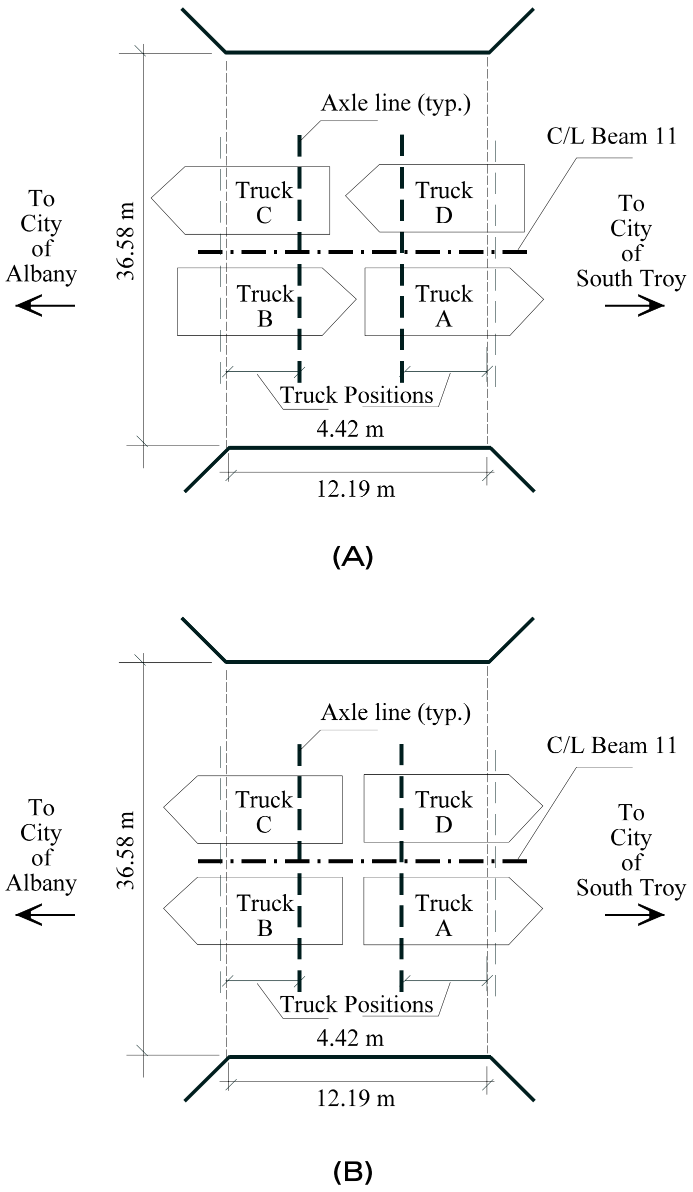


FRP laminate gages on Beam 11 at 4.42m from abutment

B. LOAD TEST

The 2001 testing was conducted using similar trucks and loading sequences to those used in the 1999 test. The average weight of each of the test trucks was approximately 196 kN (44 kips). The sequencing, in which the four trucks were designated A through D (Figure 8), consisted of Truck A, Trucks A+C, Trucks A+B+C, Trucks A+B+C+D, Trucks B+C+D, Trucks B+D, and Truck D. Since the load carrying capacity of the bridge is now known with a great degree of certainty, in the November 2001 test, only the 4.42 m position (Figure 8) from the 1999 test was used in straight and back-to-back configurations *(2)*. The total moment on the bridge due to all 4 trucks parked back-to-back at this position was about 2.75 times that induced by MS-18 loading (*6*).

FIGURE 8. Typical truck positions on the bridge: A) Straight and B) Back-to-back.



III. TEST RESULTS AND DISCUSSION

A. STRAIN GAGE RESULTS

Recorded strains on Beam11 from the 1999 before and after strengthening, and the 2001 load tests are plotted against truck moments in Figure 9. This figure shows that the 2001 test, generally, resulted in lower strains than those obtained during the 1999 test, and that the changes in beam stiffness during the three tests (before strengthening, 1999, and 2001) are very small. The figure also illustrates linear behavior and consistency of the collected strain data during the three tests.

The results from the November 1999 and 2001 tests for the steel rebar and FRP midspan gages (See Figures 5 and 7 for gage locations) are compared, respectively, in Figures 10 and 11 for various truck sequences. In agreement with the results in Figure 9, these figures also show that the November 2001 strains are generally lower than those recorded earlier in 1999. Although some of these strains are within the variations normally associated with instrumentation, they clearly show a consistency that is generally associated with data acquisition. The low 2001 strain measurement may also be attributed to slight variations in truck positions during the testing. The relatively proportional reduction in steel rebar and FRP maximum strains in the 2001 results (Figures 10 and 11), from their 1999 levels, suggests that laminate bond quality, at the instrumented locations, has not deteriorated during the two-year period between the two tests.

FIGURE 9. Strain vs moment comparisons.

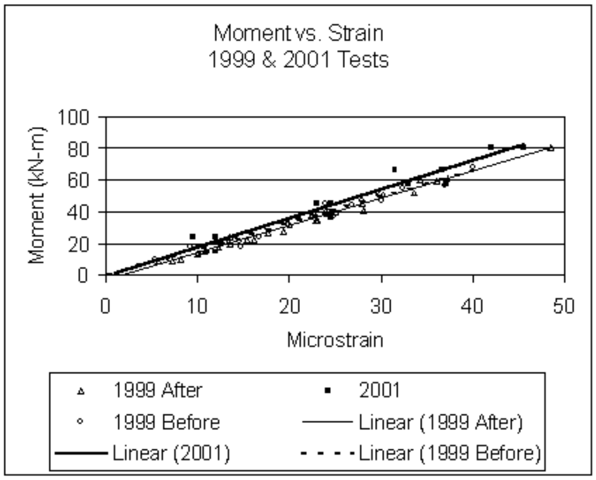


FIGURE 10. Midspan steel rebar gage readings.

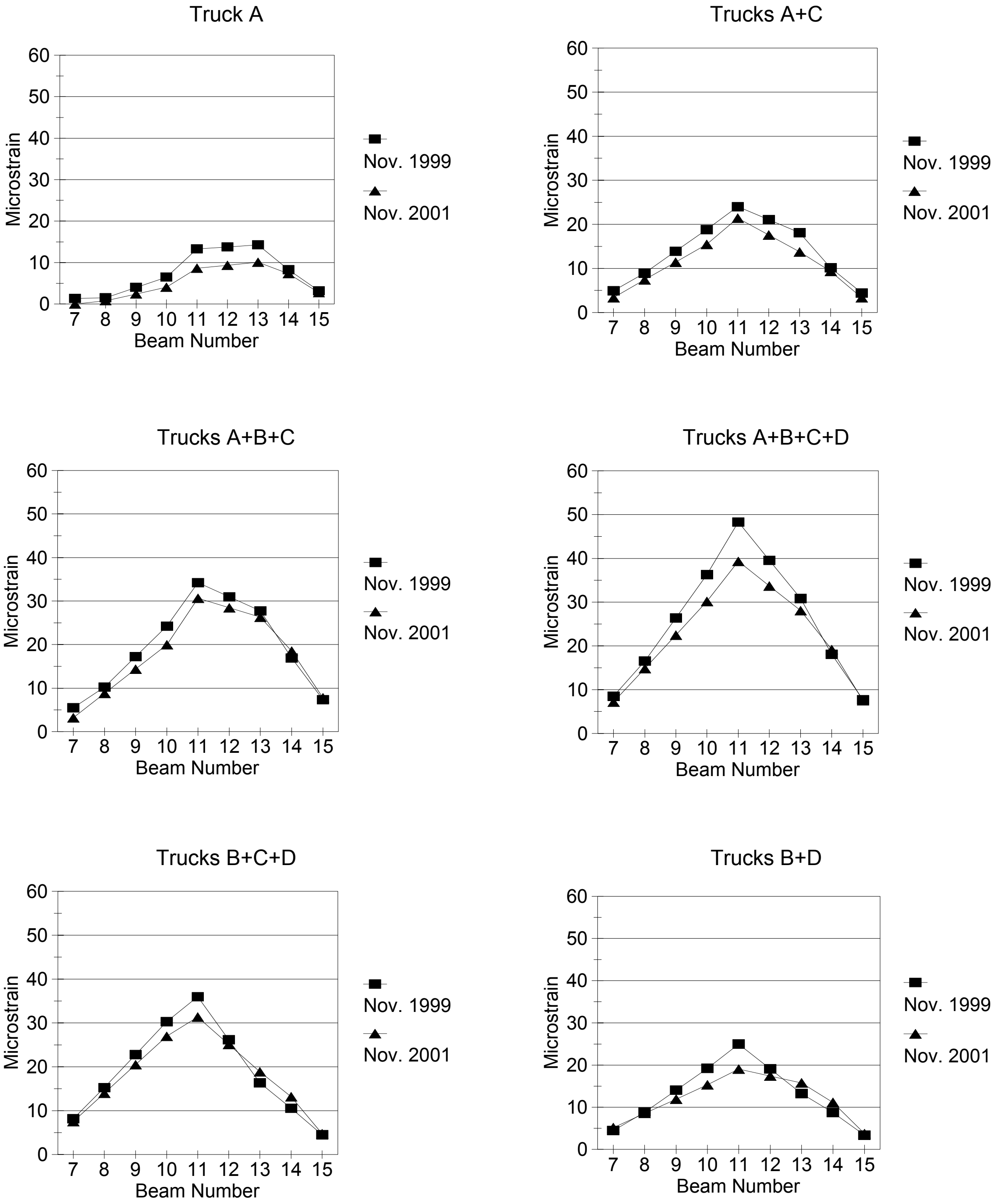
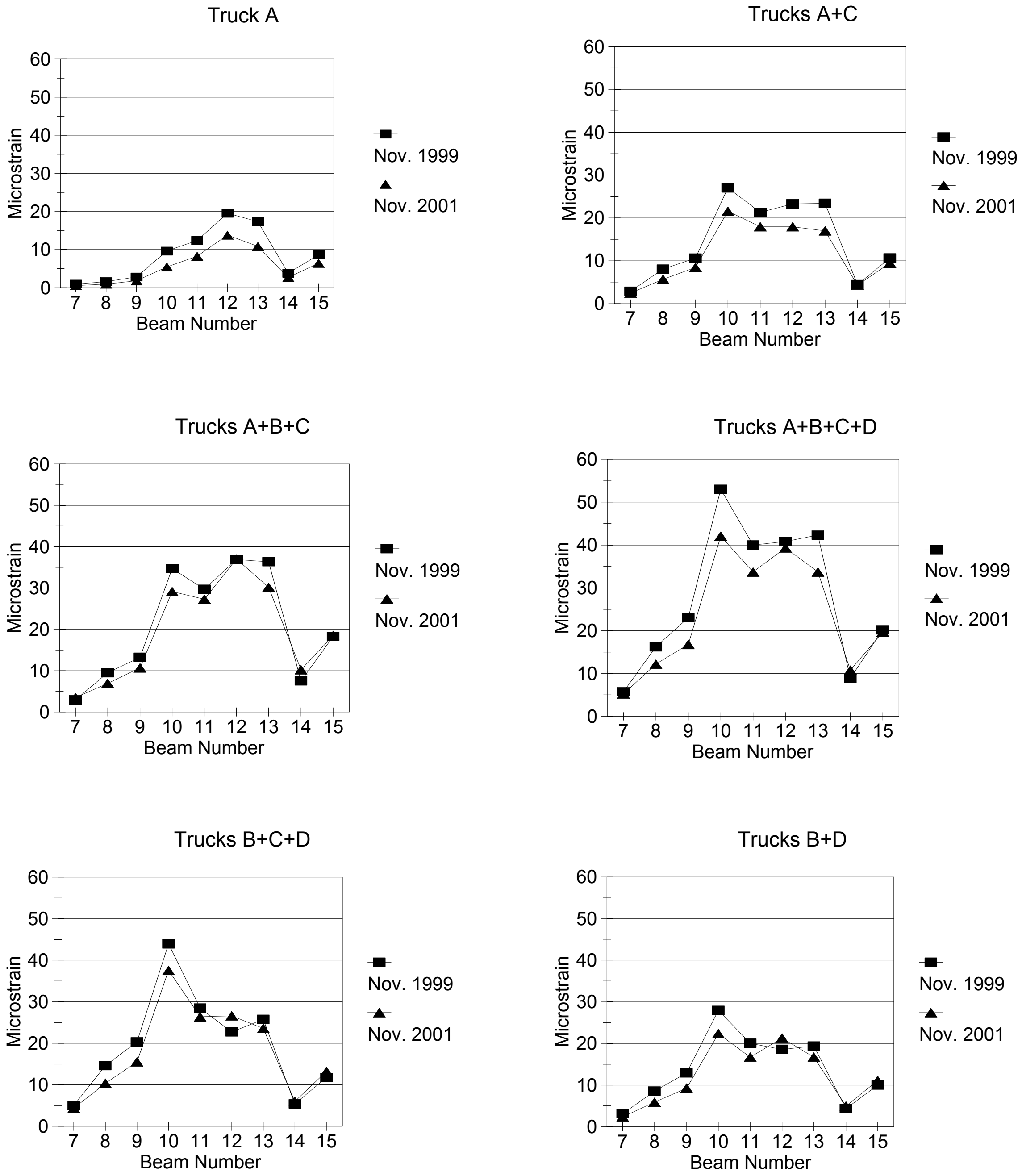


FIGURE 11. Midspan FRP gage readings.



Comparing the results for the web laminates (Figure 12), transverse laminates (Figure 13), and those mounted in the longitudinal direction between Beam 11 (Figure 14), it is noted that lower strains were recorded during the 2001 test than those measured in 1999. Similar trends were observed for longitudinal laminate strain data. See Figure 7 for the location of the FRP gages referenced in Figures 12 to 14.

FIGURE 12. Readings for web sides FRP gages.

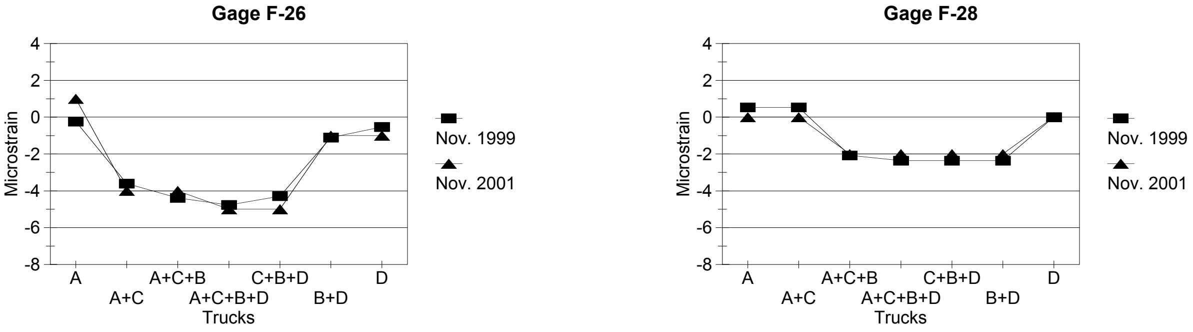


FIGURE 13. Readings for transverse FRP gages.

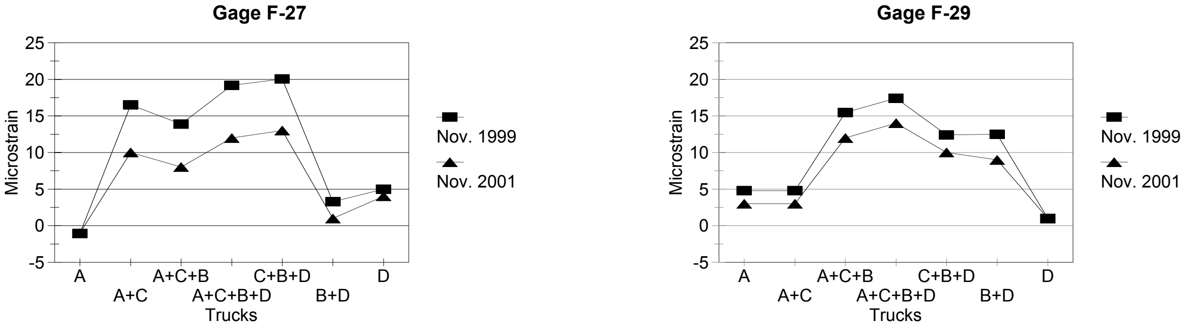
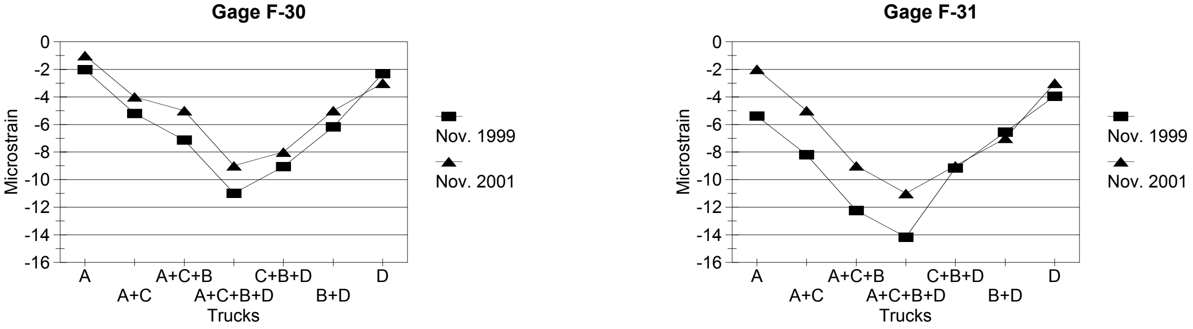


FIGURE 14. Readings for longitudinal flange FRP gages.



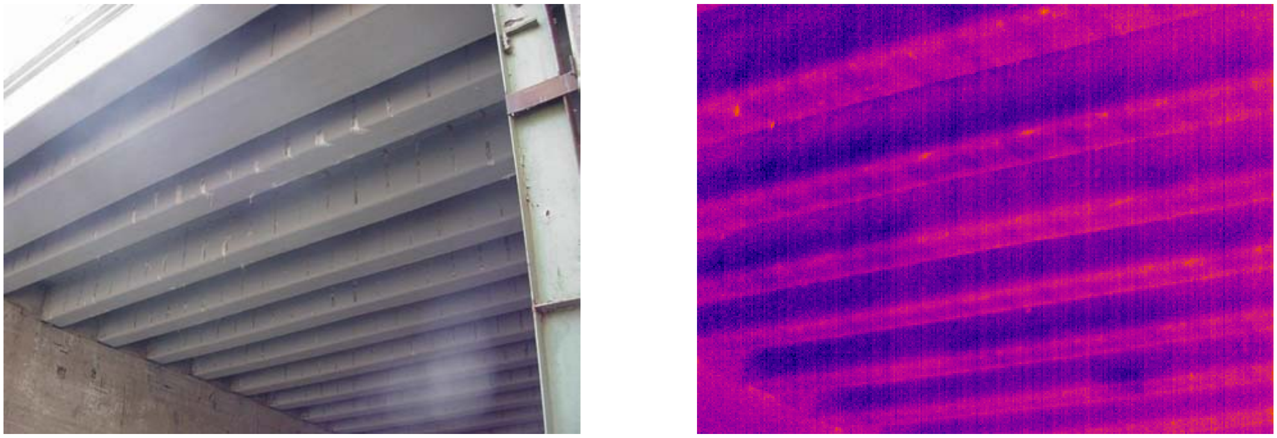
B. LAMINATE BOND TO CONCRETE

Strain compatibility can be used to assess the bond quality between the FRP laminates and concrete, by observing laminate and concrete strains at similar locations on a structure. Such a comparison at two locations, above and below the neutral axis, is shown in Table 1 for Trucks B+C+D (for maximum shear at midspan) on the bridge. Bottom concrete strains for comparison with Gage F-32 strains were calculated using Gage S-4 readings and an average location of the neutral axis. Comparing the respective percent differences for the 2001 and 1999 tests, it can be concluded that quality of the bond, at the instrumented locations, has not deteriorated during the last two years in service. Thermographic imaging using an Infrared (IR) camera did not show any serious debonding in the system laminates. Upon close observation, only small bubbles were detected in some of the camera images. A photo and a typical thermographic image of the South side beams are shown in Figures 15A and B, respectively.

TABLE 1. Comparison between concrete and laminate strains at similar locations for bond investigation (Based on Trucks B+C+D data).

Test	Truck Position (m)	Strain (με)					
		Gage C-12 Versus Gage F-30			Bottom Concrete Versus Gage F-32		
		Gage C-12	Gage F-30	Difference (%)	Bottom Concrete	Gage F-32	Difference (%)
November 1999	4.42	-6	-6	0	27	19	30
	4.42 Back-to-Back	-9	-9	0	41	27	34
November 2001	4.42	-5	-6	-17	29	20	31
	4.42 Back-to-Back	-10	-9	10	39	27	31

FIGURE 15. South side beams: A) Photo and B) Thermographic image.



(A) **(B)**

C. TRANSVERSE LOAD DISTRIBUTION

Live-load distribution factors, based on the 1999 and 2001 test results, for Beam 11 are shown in Table 2. Comparing the respective factors for the two test years, it can be concluded that the manner in which live load on the bridge is distributed has not changed, which implies that the retrofit system has not deteriorated between the two tests.

TABLE 2. Live load moments and distribution factors for Beam 11.

Trucks Position from Abutments (m)	November 1999		November 2001	
	Total Moment at Midspan (kN-m)	Live-Load Distribution Factor	Total Moment at Midspan (kN-m)	Live-Load Distribution Factor
4.42	299.0	0.204	314.5	0.206
4.42 Back-to-Back	385.7	0.208	412.2	0.208

D. EFFECTIVE FLANGE WIDTH AND NEUTRAL AXIS LOCATION

Using data from strain gages mounted on Beam 11 flange soffit (Gages C-12 and C-13), effective flange-widths for the 1999 and 2001 tests are compared in Table 3. Again, the results presented in this table, indicate the absence of any signs of deterioration in the retrofit system after two years in service.

Neutral axis locations, calculated based on the 1999 and 2001 tests results, are compared in Table 4. From this table it is noted that the neutral axis based on the 2001 results has shifted slightly upwards.

TABLE 3. Effective flange width investigation (Based on Trucks A+B+C+D data).

Truck Position (m)	Strain (με)				Effective Flange Width (m)	
	Gage C-12		Gage C-13			
	1999	2001	1999	2001	1999	2001
4.42	-8	-6	-14	-13	1.168	1.125
4.42 Back-to-Back	-11	-10	-19	-17	1.179	1.183

TABLE 4. Neutral axis investigation (Based on Trucks A+B+C+D data).

Truck Position (m)	November 1999			November 2001		
	Top Strain[a] (μϵ)	Bottom Strain[b] (μϵ)	Neutral Axis Location[c] (mm)	Top Strain[a] (μϵ)	Bottom Strain[b] (μϵ)	Neutral Axis Location[c] (mm)
4.42	-14	38	190	-13	37	181
4.42 Back-to-Back	-19	48	198	-17	44	194

[a] Gage C-13 strains; [b] Average Gages S-4 and S-5 strains; [c] Measured below flange soffit.

IV. CONCLUSIONS

In November 2001, the bridge carrying Route 378 over the Wynantskill Creek in New York, was load tested to monitor changes in the bridge FRP retrofit system, after being in service for two years. The system was installed in 1999 to contain freeze-thaw cracking and improve flexural and shear behavior of the deteriorated reinforced-concrete T-beam bridge structure. Changes in the quality of the bond between the FRP laminates and concrete, at instrumented locations were investigated, and those in the retrofit system were studied by observing changes in transverse load distribution, effective flange width, and neutral axis location. The 2001 load test indicated that recorded strains were generally lower than those measured during the 1999 test. The results also indicated that the quality of the bond between the FRP laminates and concrete, and effectiveness of the retrofit system have not changed after two years in service. Thermographic imaging using an Infrared camera, provided images which supported this conclusion on bond quality.

ACKNOWLEDGMENTS

Instrumentation and data collection for this project were conducted by George Schongar and Harry Greenberg of the Transportation Research and Development Bureau. Timothy Conway, Regional Structures Engineer, and his staff assisted with the testing and traffic control.

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