INNOVATIVE FIBRE REINFORCED BRIDGE DECK MODULES

Heather Crocker, ISIS Canada, Winnipeg, MB
Emile Shehata, Wardrop Engineering Inc., Winnipeg, MB
Rick Haldane-Wilsone, Wardrop Engineering Inc., Winnipeg, MB
Aftab Mufti, ISIS Canada, Winnipeg, MB

ABSTRACT

The consideration of glass fibre reinforced polymer (GFRP) bridge decks as a replacement for conventional reinforced concrete bridge decks is on the rise. This is because FRP bridge decks are easier to install, lightweight, durable and non-corrosive. Development of an optimal design will ultimately address the high cost that is associated with the FRP materials and fabrication.

This paper is an overview of an experimental program that deals with the development of GFRP bridge deck modules. Two separate full-scale decks were tested under a simulated AASHTO HS30 design truckload. Both static and cyclic loading tests were performed.

INTRODUCTION

Deterioration of bridge decks is of critical importance in North America and Europe. This is a result of bridge decks reaching the end of their service life and degradation due to lack of proper maintenance, environmental conditions, or poor initial construction (Zureick et al, 1995).

It is estimated that with the use of road salt, the life of a conventional bridge deck is reduced to ten years. At this point, repair or replacement is required and this can be as high as 75% to 90% of the total annual maintenance cost of the structure (Karbhari et al, 2001). Current trends in North America have seen not only an increase in truckloads, but also an increase in the number of traffic lanes to meet the demands of a growing population. When repair or replacement is imminent, there is not only the associated cost of materials and labour, but also the cost of losses due to delays and detours. GFRP bridge decks are a viable alternative that resolve many of these identified problems.

Development of a new state-of-the-art FRP bridge deck was undertaken by Wardrop Engineering, Winnipeg, Manitoba and Faroex Ltd., Gimli, Manitoba in co-operation with ISIS Canada at the University of Manitoba.

An experimental program was undertaken to study the behaviour of the GFRP bridge deck recently patented in the United States (US patent No.6151743). The research and development project, described in this paper is founded on the evolution of four generations of the bridge deck modules. Based on the behaviour observed in the first generation, second and third generations were fabricated and tested. Testing of the first two generations was performed on three-tube deck modules using two orientation schemes, with and without outer plates. From these results, the behaviour of the various deck components was investigated. The third generation deck investigated the effects of filament-winding the entire section to produce components that would resist bending. The fourth generation deck was produced with the optimum amount of fibres, resulting in the most cost-effective deck of all four generations. Static tests were performed on all generations, with the exception of the third generation in which cyclic loading was performed to determine the effect of fatigue. The module was fatigued to 2,000,000 cycles with a load varying between 10% and 135% of the service load, and finally tested to failure. Bending in the transverse directions was investigated for the last two generations.

The performance was evaluated based on load capacity, mode of failure, deflection at service load level, strain behaviour, and stiffness degradation under cyclic loading. All decks tested exceeded the requirements to support the HS30 design truckload, as specified by AASHTO, with a margin of safety.

MATERIALS & FABRICATION

Two decks were tested. The third generation deck (F9-1) tested consisted of nine triangular filament-wound tubes (seven of which were equilateral triangles) 200 mm in height, as shown in Fig. 1.

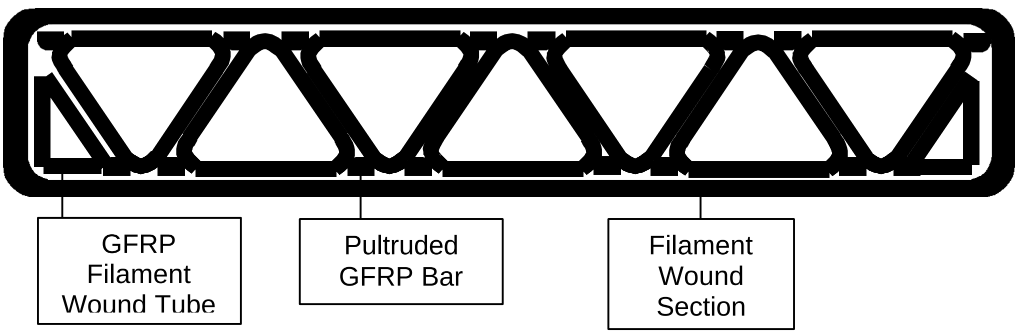

Figure 1. Schematic of Third Generation Deck Cross Section

The tubes were 8-layer elements, wrapped in a [90/±45/±10/±45/90] sequence. Epoxy resin was used to adhere the tubes together. Due to the rounded corners of the triangular sections, pultruded GFRP bars with a roughened surface were placed in the section to prevent voids that occur due to the rounded corners of the triangular elements. Finally the whole section was wrapped by a 24-layer faceplate in a [90/±45/±10/±10/±45/±10/±10/±10/±45/±10/±10/±45/90] sequence.

The material properties of the fibres and the epoxy used in both decks are given in Table 1 and 2.

Table 1. Glass Fiber Roving Properties

Property	Value
Specific Gravity	2.624
Tensile Strength [MPa]	1700
Tensile Modulus [GPa]	72.4
Strain at Failure	2.3%
Poisson's Ratio	0.22
Thermal Expansion [10-6/°C]	5.8

Table 2. Epoxy Resin Properties

Property	Value
Specific Gravity	1.163
Tensile Strength [MPa]	64.8
Tensile Modulus [GPa]	3.15
Poisson's Ratio	0.27
Percent Elongation	9.9
Heat Deflection Temperature [°C]	103

The fabrication process for specimen F9-1 is summarised as follows:

1. 3.5 m long triangular shaped styrofoam mandrels were custom-made.

2. The mandrels were filament wound with seven layers of wet glass fibre rovings and an eighth dry wound layer to produce the eight layer laminate designed for the tubes.

3. Nine triangular elements (seven equilateral triangles and two end triangles) were placed in the appropriate location with the GFRP bars between the triangular elements.

4. The whole system was placed on a mandrel and filament wound, as shown in Fig. 2.

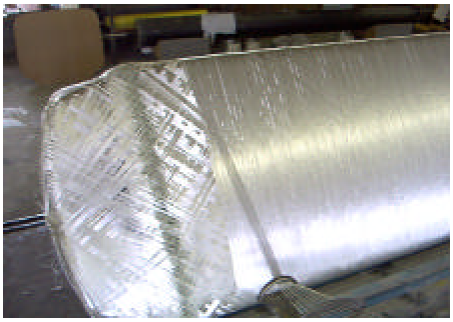

Figure 2. Filament Winding of Entire Module

5. Upon completion of assembly, the deck was wrapped, sealed in a plastic bag and infused with resin.

6. The deck was cured at 180°F for 8-10 hours, while a vacuum pump worked to remove excess resin from the deck, and minimize voids. When curing was complete, the deck module was cut to the desired length.

The second design tested (F10) consisted of seven triangular filament wound tubes that were 200 mm in height, 12 filler bars and two pultruded plates. A schematic of the deck cross-section is shown in Fig. 3.

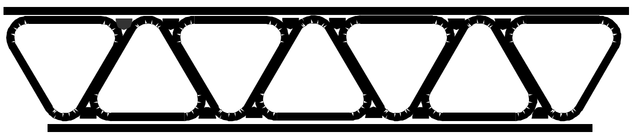

Figure 3. Schematic of F10 Cross Section

The tubes are 8-layer elements, wrapped in a [90/±45/±10/±45/90] sequence. Epoxy resin was used to adhere the tubes together. Pultruded GFRP bars with a roughened surface were placed where voids posed a problem.
Finally, the entire section was wrapped by a 24-layer faceplate in a [90/±45/±10/±10/±45/±10/±10/±10/±45/±10/±10/±45/90] sequence.

The fabrication process used for the fourth generation is summarised as follows:

1. Pultruded laminates were fabricated and assembled together to create the top and bottom plates.

2. Filament wound triangular elements were fabricated in the same manner performed for specimen F9-1.

3. Fibre optic sensors and conventional strain gauges were placed on the interior of the bottom plate as shown in Fig. 4. FOS and conventional strain gauges were also placed on the interior of the top plate in both longitudinal and transverse directions.

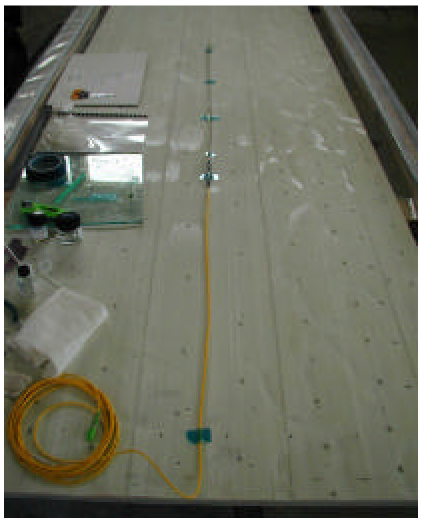

Figure 4. Location of Fibre Optic Sensor in F10

4. Seven triangular elements were placed on the GFRP plate and bonded with added resin, as shown in Fig. 5. The GFRP bars were placed between the triangular elements.

Figure 5. Placement of Components

5. The top plate was positioned and bonded with added resin. Upon completion of assembly, the deck was wrapped and sealed in a plastic bag for resin infusion.

The deck was cured at 180°F for 8-10 hours, while a vacuum pump worked to remove excess resin from the deck and minimize voids. When curing was complete, the deck module was cut to the desired three-meter length.

TESTING

The third generation deck (F9-1) tested was simply supported with a span length of 3 m and a width of approximately 1.2 m. A single 250 x 570 mm point-load was applied under stroke control at 0.75 mm/min. The load was applied using a 2000 kN machine as shown in Fig. 6.

Figure 6. Test Setup for F9-1

The point load simulated a wheel load area of an AASHTO design truck. Cyclic loading was performed to observe any loss in stiffness. To accomplish this objective, static tests were performed intermittently to investigate flexural strength, stiffness, fatigue behaviour, residual strength after loading, and failure modes.

The specimen was subjected to two million cycles with a load varying between 10% and 135% of the HS30 wheel load (service load level is 140 kN) at a frequency of 0.5 to 0.9 Hz. Static tests were performed at 0 cycles, 1,000 cycles, 250,000 cycles, 500,000 cycles, 750,000 cycles, 1 million cycles, 1.2 million cycles, 1.5 million cycles, 1.75 million cycles and at 2 million cycles. During the static tests the strains and deflections were measured up to the service load level. Two million cycles is specified by AASHTO as representing the life time of a bridge. This relatively low number of cycles is compensated with the adoption of high fatigue loads. The fatigue tests and static tests were performed at the McQuade Structures Lab at the University of Manitoba in Winnipeg, Manitoba.

Static testing was performed on the second specimen (F10). The specimen was set up in the same manner as specimen F9-1 as shown in Fig. 7.

Finally both tested decks were cut in the transverse direction into five specimens. These were tested to determine the flexural rigidity of the deck in the transverse direction.

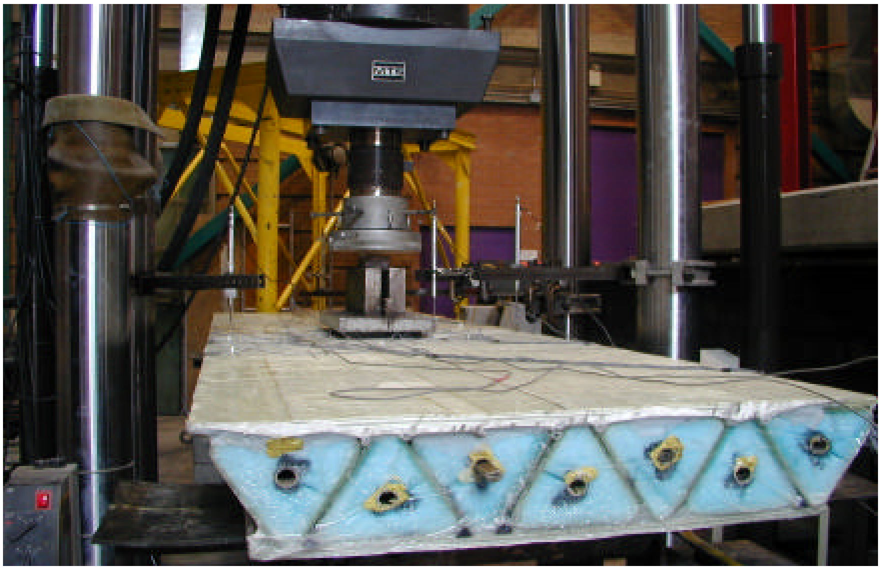

Figure 7. Test Setup for F10

INSTRUMENTATION

Specimens F9-1 and F10 were instrumented with 15 electrical resistance strain gauges one placed transversly and 14 placed longitudinally. The strain gauges were placed along the top and underside of the specimen to determine strain behaviour.

Four linear voltage displacement transducers (LVDTs) were placed on the top of the specimen. One was placed along the longitudinal centre line over the west support, another along the transverse center line close to the footprint. Finally, two were placed at both edges of the specimen along the transverse center line.

RESULTS

For specimen F9-1, after two million cycles, the increase in deflection with respect to initial values was under 5%, as shown in Fig. 8.

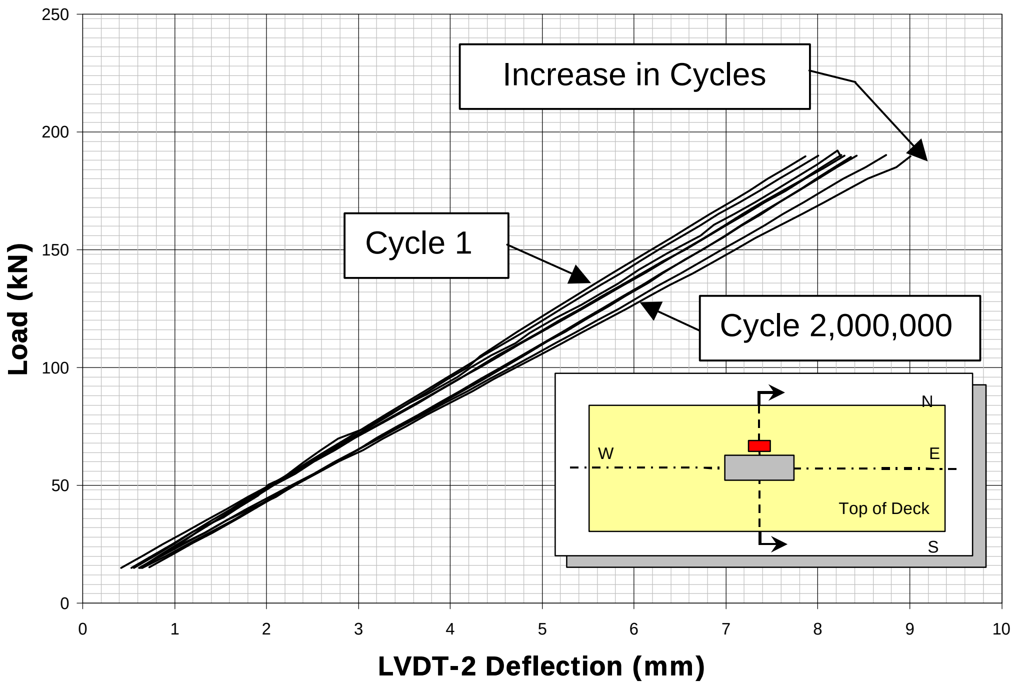

Figure 8. Load Deflection Fatigue Behaviour of Third Generation Deck

The experimental results showed that all decks demonstrated similar linear behavior under the applied load.

The specimen was then tested to determine the ultimate capacity. The specimen was loaded to 730 kN when it was observed that severe damage had occurred in the loading frame. Therefore the test was stopped. Up to 730 kN, the specimen showed linear behaviour with no loss in the stiffness and with no local damage. Testing continued using a stronger frame and the specimen reached failure at 847 kN with a maximum deflection of 40 mm as shown in Fig 9.

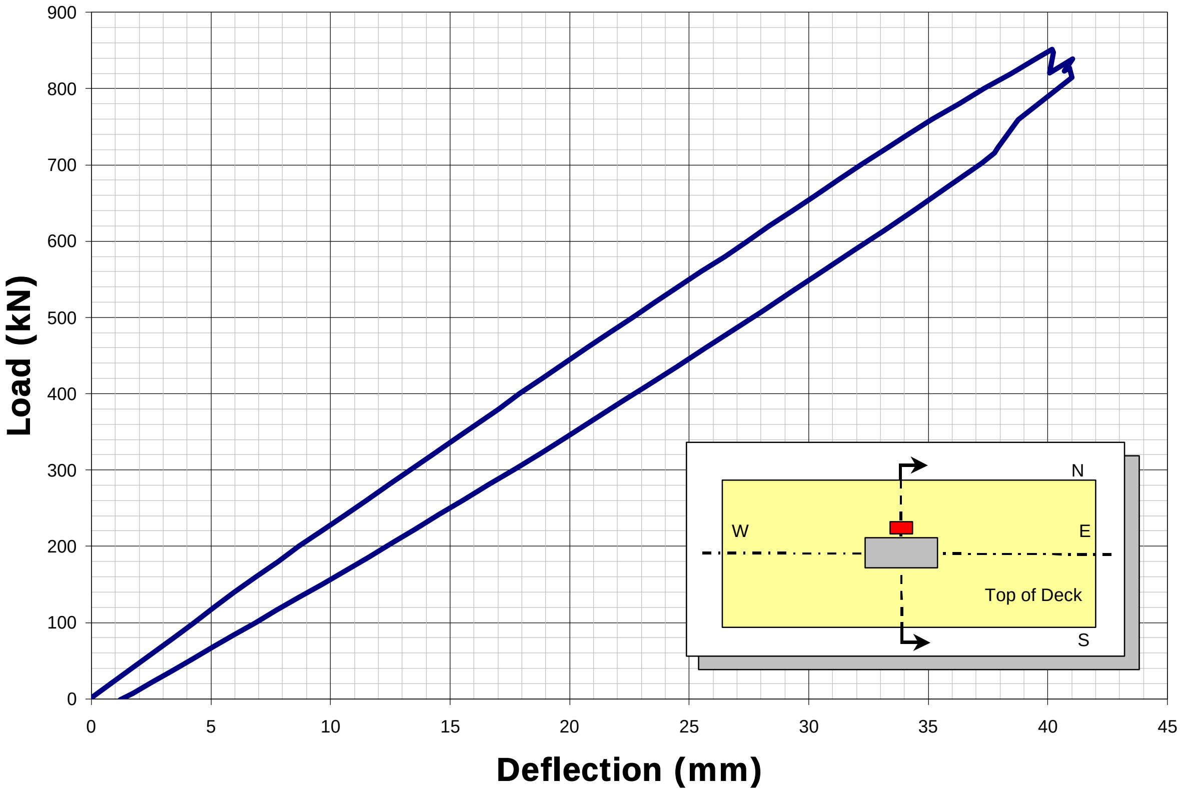

Figure 9. Load Deflection Behaviour of F9-1 Post Cyclic Loading

The mode of failure was delamination between two of the middle triangular elements under the load as shown in Fig 10.

Figure 10. Failure of F9-1

The fourth generation deck failed at 780 kN, due to delamination that lead to buckling and eventually punching around the loading plate, as shown in Fig. 11.

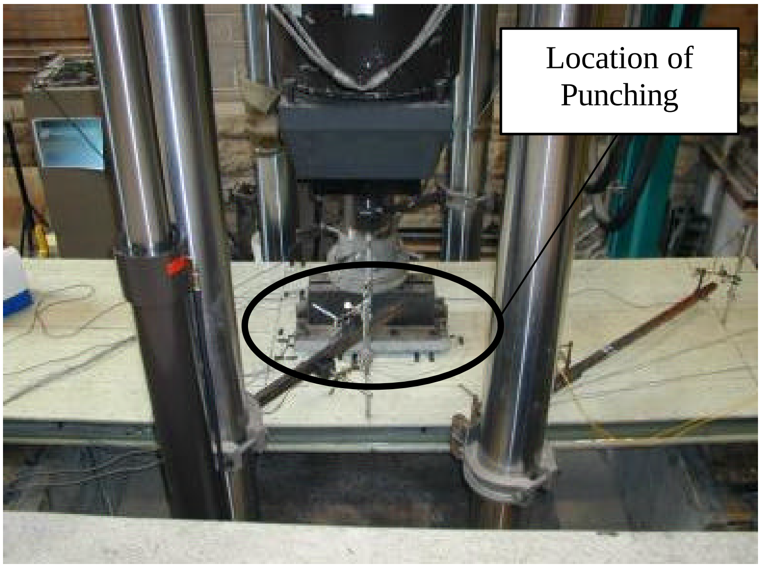

Figure 11. Punching Failure of F10

Load versus deflection for the fourth generation deck is shown in Fig. 12. Loading was continued on the specimen until there was a large drop in load at 620 kN.

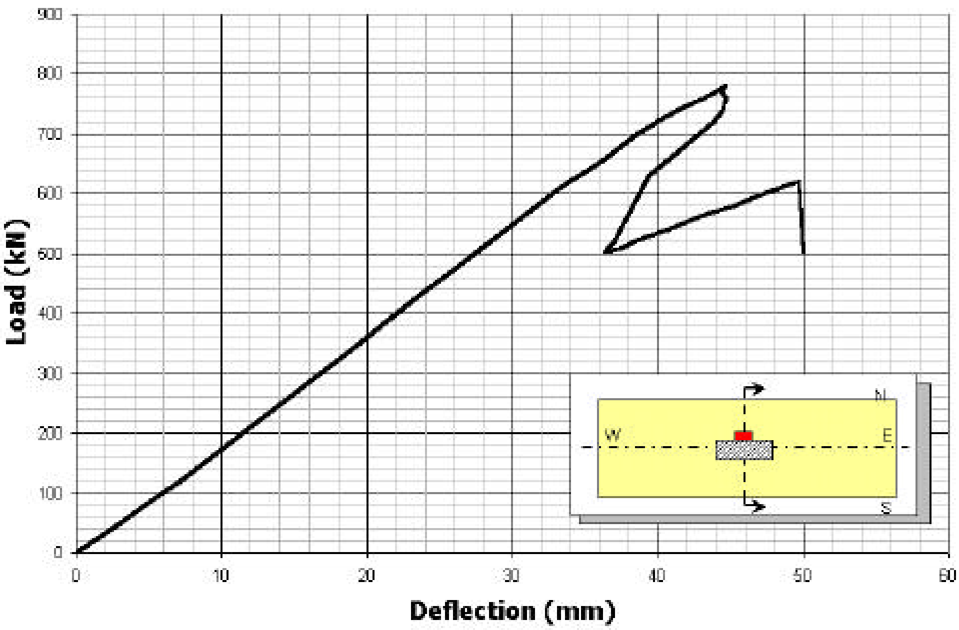

Figure 12. Load Deflection Behaviour of F10

Once 620 kN was reached, buckling of the top plate occurred, as shown in Fig 13.

Figure 13. Bucking of Plate in Deck F10

CONCLUSION

This paper detailed the fabrication process and discussed the experimental program dealing with GFRP bridge deck modules. Two different designs were tested to enable a bases for comparison. Cyclic loading was performed in order to investigate the long term practical use of GFRP decks. The results obtained indicate that GFRP bridge deck modules are a viable alternative to conventional reinforced concrete bridge decks.

ACKNOWLEDGEMENTS

The authors wish to acknowledge funding received from ISIS Canada, a Network of Centres of Excellence, and the Industrial Research Assistance Program (IRAP), as well as the time, materials, financial support and collaboration provided by Wardrop Engineering Inc. and Faroex Ltd.

REFERENCES

1. American Association of State Highways and Transportation Officials, *LRFD Bridge Design Specifications*, 1996, 16th Edition.

2. Karbhari, V.M. (2001). "Processing and Performance of Bridge Deck Subcomponents Using Two Schemes of Resin Infusion," *Composite Structures,* 51, 257-259.

3. Mallick, P.K. (1993). Fiber-Reinforced Composites: Materials, Manufacturing and Design. Pub. Dekker, 566 pgs.

4. Zureick, A.H., Shih, B., Munley, E. (1995). "Fiber-Reinforced Polymeric Bridge Decks," *Structural Engineering Review*, Vol. 7, No. 3, pp. 257-266.