DURABILITY CHARACTERISTICS OF THE TECH 21 BRIDGE

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ABSTRACT: Advanced fiber-reinforced polymer composite has been in use by the defense and marine industry for an extended period of time and as a result there is substantial data regarding its long-term durability characteristics for these specific applications. It has had limited years of service life utilization regarding the harsher infrastructure environment. The durability characteristics of an all-composite vehicular bridge, constructed in 1997, are discussed. In addition to the field observation over the last twenty years, accelerated coupon tests exhibit excellent performance of the reference bridge superstructure made of advanced FRP composites materials.

1 INTRODUCTION

It is well known that the deterioration of the existing infrastructure cost the nations billions of dollars for repair and replacement. As a result, the need for new materials and technology that could be implemented expediently and enhance the functional longevity of roadways and bridges is recognized. Dutta, et al. [2003] reveal that of all bridge superstructure elements, bridge decks require the maximum maintenance due to a combination of degradation of the deck system, deterioration of wearing surface, increased traffic volume and load, and environmental impact. Won, et al. [2004] state that corrosion of steel rebars is the major cause of deterioration in reinforced concrete structures. This problem is specially escalated when the concrete structures are in direct contact with water such as marine structures or concrete bridges.

Recently, the use of fiber-reinforced polymer (FRP) composites has markedly increased due to their high strength and stiffness-to-weight ratios, corrosion resistance, environmental durability, and inherent tailorability [Karbhari, 2001]. The application of FRP composite materials in civil and transportation infrastructure dates back to 1950s when they were utilized as specialized alternative measures for reinforcing concrete [Harries, 2006]. Their use reached new heights in 1980s, both as internal and external reinforcing materials in relation to concrete structures, and since mid-1990's, they have been considered as viable systems for use in civil and transportation infrastructure applications [Harries, 2006]. In fact, construction industry was the second largest consumer of FRP composites in 1999, representing more than 35% of the global market [Weaver, A., 1999].

It has been determined that the short term behavior of FRP composites depend upon the types of fibers and resins, fiber volume fraction, fiber orientation, manufacturing process, and production quality control process [NCHRP 2003]. The NCHRP report [2003] further reveals that the degradation accelerates under harsh environmental conditions. Also, material properties of FRP composites change over time. Four factors have been identified that affect the environmental durability of FRP composites including the freeze-thaw condition, temperature, humidity, and presence of alkaline environment [NCHRP, 2003]. In addition, the mechanical properties of the FRP composites are often influenced by aging, typically in the absence of load. It has been found [NCHRP, 2003] that the aging is caused by the changes in the chemical and physical properties of polymers due to degradation of the fiber-resin interface, temperature changes, moisture ingress, and reactions with foreign objects.

In this paper, the durability characteristics of an all-composite vehicular bridge that was installed in July 1997 will be presented. The bridge has been in existence for nearly 17 years and has been monitored extensively during the first five years via a combination of vibrating wire and fiber optic sensors. Although, the intrusive health-monitoring was discontinued due to lack of subsequent funding, the bridge performance has been monitored occasionally via field inspection and sounding. The overall integrity of the bridge superstructure is evident. Hallmarks of the Tech 21 Bridge will be discussed herein in the framework of durability issues on the 17th anniversary of its conception.

2 BRIDGE SUPERSTRUCTURE

The reference bridge entails a single-span, two-lane, all composite vehicular structure that is located near the City of Hamilton in Butler County, Ohio. The superstructure spans 9.67 m, measured center-to-center of bearings, with an overall 10-m length. The entire width of the bridge deck is 7.3 m, measured face-to-face of guardrails. The bridge system, shown in Figure 1, consists of a sandwich deck configuration along with integral trapezoidal beams, as detailed below.

Figure 1. Side View of the Tech 21 Bridge.

The bridge deck is composed of longitudinally oriented GFRP trapezoidal sections fabricated by pultrusion, bonded together between adjoining surfaces and sandwiched between top and bottom GFRP ace sheets applied in a wet lay-up process by ACME Fiberglass® in Hayward, California. Geometry and laminate assignment of a representative section of the deck are shown in Figure 2. The face sheets are continuous across the width of each of the three deck sections. Furthermore, the upper face sheet consists of three plies arranged in the 0-90-0 degree orientation, while the lower face sheet is made of two plies in 0-degree direction, each being 2.3 mm thick. The intent of using an additional ply in the top face sheet is to guard against any potential degradation from placement of the asphalt-wearing surface. Ashland Chemical Company's 604T type resin is employed for both face sheets, primarily due to its high-quality mechanical and laminating properties, fire retardancy, and low cost.

A typical cross-section of the U-shaped or trapezoidal box beam is depicted in Figure 3. Other unique features of the Tech 21 Bridge include the continuous glass fiber reinforcement across the entire beam section, with additional fiber layers placed in the bottom flange of the beam. The beams were fabricated via hand lay-up process on a male tool and cured at room temperature. The above flange and web sections of the box girder consist of six plies of TLX fabric with alternating orientation between the 0-degree (i.e., the longitudinal direction) and perpendicular to it (i.e., in 90-degree direction). Accordingly, the total thickness for these two sections equals to 1.37 cm. The cap section, on the other hand, involved five plies of TLR (unidirectional) fabric between the TLX plies, all in the longitudinal direction with a total thickness of 2.90 cm.

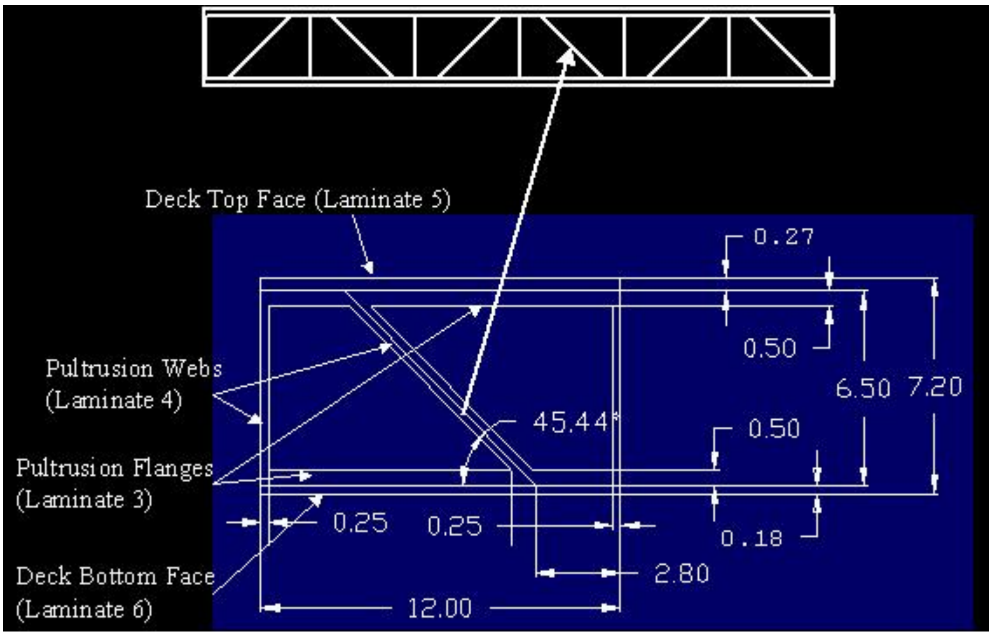

Figure 2. Section Geometry and Laminate Assignment.

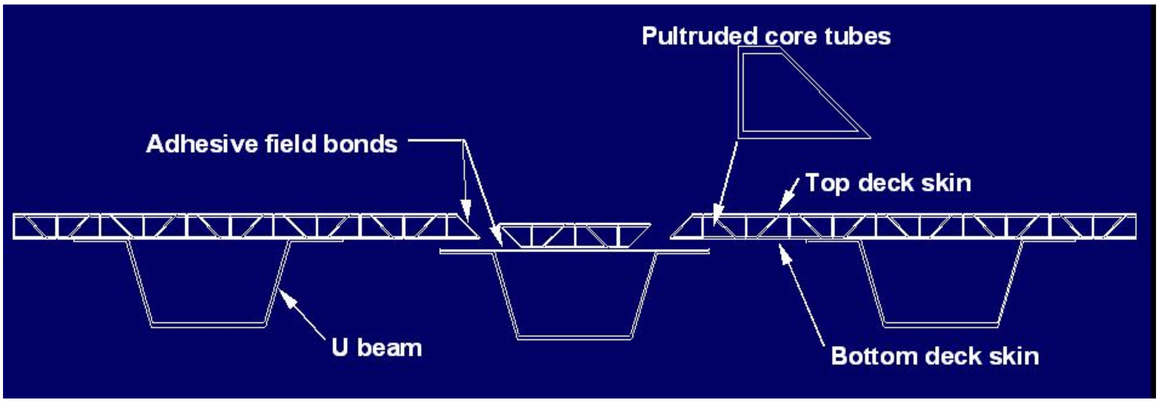

Figure 3. Typical Trapezoidal-Shape Cross-Section.

The trapezoidal configuration provides enhanced transverse stiffness due to its high torsional resistance in comparison to the typical wide-flange sections of the steel industry. Furthermore, the trapezoidal shape eliminates the need for intermediate diaphragms. Also, the closed section enables the shear panels to resist local buckling modes more effectively than the comparable wide-flange steel sections, while allowing for the laminate to be engineered with a higher percentage of angle plies – to enhance the shear stiffness of the diagonal webs.

3 INSTRUMENTATION, LOAD TESTING, AND HEALTH-MONITORING

A hallmark of the Tech 21 Bridge was the extensive instrumentation plan that was implemented within the modules during and immediately after the manufacturing process. This entailed a combination of a group of vibrating wire sensors, hereafter referred to as the "primary system," and the fiber-optic sensors that will be designated as the "auxiliary system." The primary system involved a series of vibrating wire transducers and linear variable displacement transducers (LVDT) that were mounted on preset locations on the structure. The re-usable Wheatstone bridge transducers, mounted on the bridge via removable tabs using a high-strength adhesive, had 75-mm gage length and were calibrated to an accuracy of ± 2% of the NIST Specifications. The DCT-1000 ADC model LVDT's, operating from a ± 15 volt DC power supply having a range of ± 25 mm and possessing a resolution accuracy of approximately 0.025 mm, were mounted on wood blocking set on top of step ladders.

A series of short-term live-load tests was conducted via both single and tandem-axle trucks during both winter and summer seasons to identify the influence of temperature on the results. A routine check was made to verify the proper functioning of all the gages and the data acquisition system. The ambient temperature at the time of actual testing was recorded. The wheel spacing and weight distribution for each individual application were documented. The detailed analysis of the test results if beyond the scope of this presentation. It suffices here to illustrate a typical structural response history in terms of truck wheel load versus microstrain for one of the sensors, as shown in Figure 4. Overall, it appeared that the maximum response remained below 250 microstrains. Furthermore, it is apparent that the response history of the bridge to the crawl speed tests is consistent with the stationary truck deflections. These test results are in compliance with those conducted at other times, confirming the healthy response of the bridge.

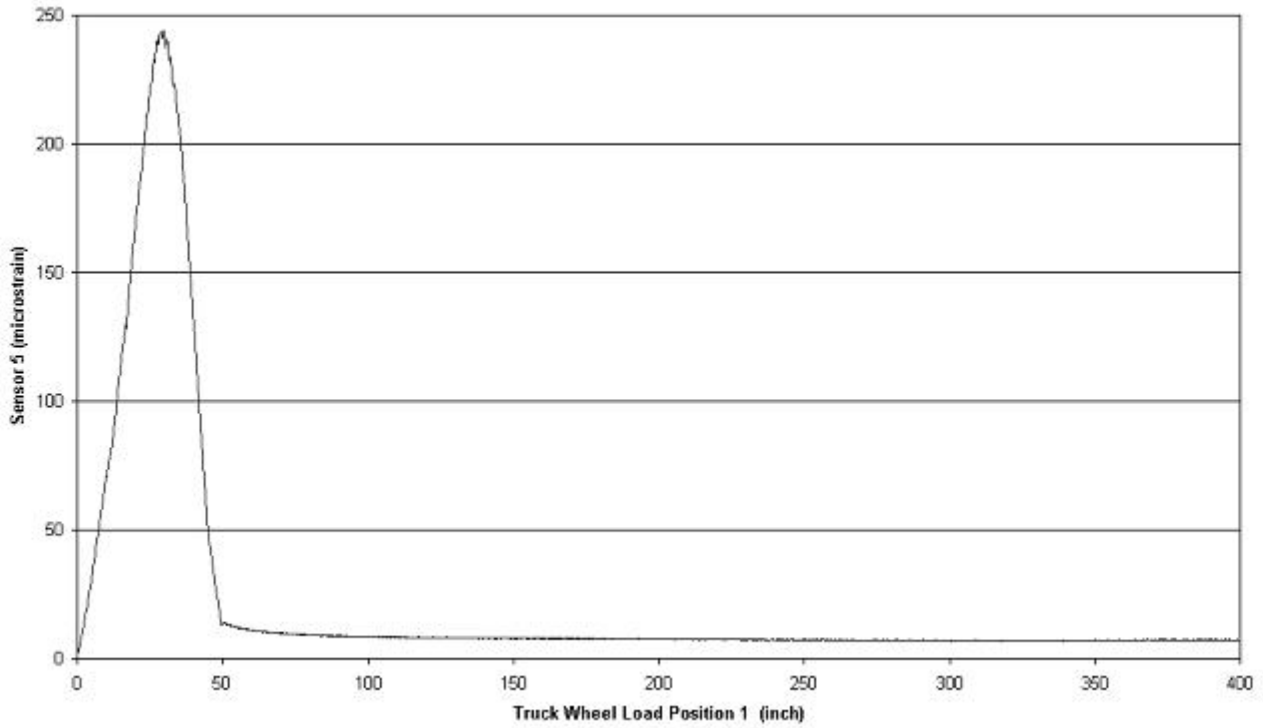

Figure 4. Bridge Response Due to Truck Load Test at Crawling Speed.

The long-term structural health-monitoring instrumentation plan, involving a combination of vibrating wire sensors and fiber-optic sensors, was intended to screen deformations and automatically relay a warning in case the signals would exceed a preset threshold amplitude. In addition, the health-monitoring program enabled the continuous measurement of temperature variation along with creep and other environmental factors such as freeze/thaw cycles. The temperature variation over time for a representative sensor is exhibited in Figure 5. The displayed results reveal the narrow range of microstrain variations throughout the year. The overall difference in maximum temperature response is less than 400 microstrain, which is merely the same as the impact of a single truck load on the bridge.

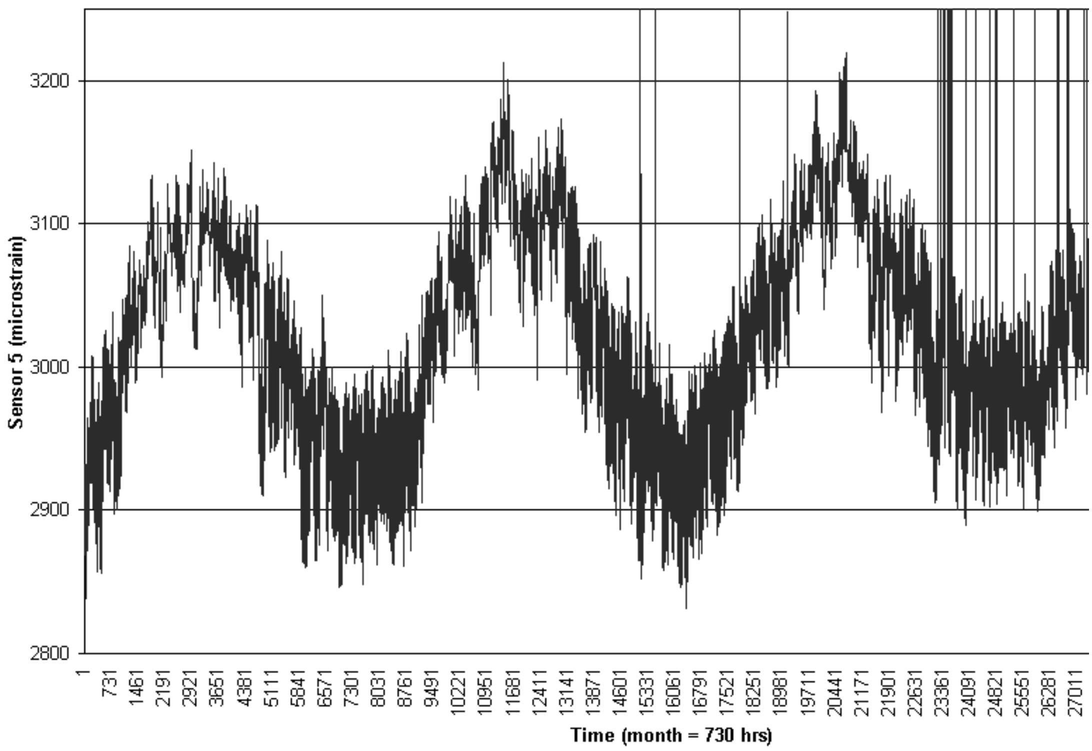

Figure 5. 44-Month Temperature Variation of a Representative Sensor

4 ADDITIONAL OBSERVATIONS IN RELATION TO THE DURABILITY

The above-mentioned auxiliary health-monitoring system via fiber-optic sensors provided the platform for identifying additional insights concerning the durability characteristics of the bridge superstructure besides those discussed in the preceding section. A total of 18 fiber optic Bragg grating sensors were installed which measured axial strain at the bottom flanges of the beams. These sensors were embedded within the structure to monitor long-term creep or permanent set, by way of detecting the shift of a specific wavelength of light attributed to any movement of the structural elements. Moreover, a total of four sapphire chemical sensor assemblies were installed for detecting moisture and chemical incursion into the adhesive bonds that were applied to join the three different sections during the field assembly. These latter set of sensors, based on infrared spectroscopy, were embedded within the material of bridge to track any moisture incursion along the bondlines and to verify the impact of freeze-thaw cycles. Unfortunately, two of the sapphire sensors, located on the south side of the beam, were damaged during the bridge assembly. The remaining two sensors, located on the north side of the beam, continued to be fully operational. The data compiled from these functional sensors disclosed that the bondline is in stable condition (Thomson, 1999). Also, it was determined that significant curing of the bondline epoxy occurred following initial installation readings.

The live load strain data from Bragg grating sensors correlated well with those of the primary system based on the vibrating wire sensor technology (Thomson, 1999). In addition, the long-term monitoring data from the Bragg grating sensors coincides well with the temperature variation over the cycles measured. Most importantly, the chemical sensors demonstrated that the adhesive fully cured in time and prohibited the penetration of the moisture and other chemicals into the bondline.

In view of the analysis of preceding field data, collected via a combination of different vibrating wire and fiber optic sensors during the first few years, along with on-site inspection throughout the last 10 years, it is evident that the Tech 21 Bridge has provided a better insight concerning the durability of the FRP composite materials for civil engineering construction. The performance of the superstructure components including the composite deck and associated U-beams are within acceptable strain levels under the daily and yearly effects of alternating temperature cycles, climatic changes, and environmental conditions. Furthermore, the quality of exposed surfaces remains superior with no visible signs of degradation, and all strain gages reported small positive strain shifts. It was also determined that the measured bending creep due to dead load correlates well with predictions from published creep data, forecasting only 2.5 mm sag over 50 years.

5 CONCLUSIONS

The following conclusions are drawn from the analyses of combination of short-term live-load testing, long-term structural health-monitoring via both vibrating wire and fiber-optic sensor technologies, and on-site inspections of the Tech 21 Bridge during last decade:

- The influence of seasonal temperature fluctuation was inconsequential on the bridge superstructure, resulting in a mere one truck load impact.
- Measured bending creep due to dead load correlated well with the predication from published creep data, forecasting only 2.5 mm sag over 50 years.
- In nearly twenty years of service, there are no visible signs of degradation, revealing excellent performance of the FRP composite material used for infrastructure application, subjected to harsh environmental conditions.
- The structural response regarding the composite deck and associated U-shaped beams are within acceptable strain levels under the daily and yearly effects of alternating temperature cycles.
- It has been proclaimed that there is a lack of confidence among the civil engineering community in relation to the composite materials for infrastructure applications due to inadequate long-term durability database. It is hoped that the current endeavor will contribute to bridging that gap and enriching the relatively long-term durability database.

6 REFERENCES

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