Development of Carbon Fiber Reinforced Polymer Bridges in USA

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Summary

During the last two decades, ten highway bridges were built with carbon fiber reinforced polymer (CFRP) components in the USA. Extensive research work and in-depth analysis were executed with the construction of each bridge to ensure both safety and longevity. Six bridges are instrumented with multiple deflection, strain, and load sensors that capture the response of the bridges under different traffic and environmental conditions. More than twelve years of field monitoring data is currently available and is being utilized in the development of national guidelines for the design and construction of highway bridges with CFRP reinforcement.

Keywords: post-tensioning; anchors; bridges; CFRP; infrastructure; corrosion; pre-tensioning.

1. Introduction

In regions with harsh environmental conditions, corrosion of steel reinforcement and prestressing strands poses major safety, durability, and financial concerns. Researchers all over the world have been persistently exploring corrosive-resistant alternatives to steel reinforcement. Special thoughtfulness was dedicated to composite materials and particularly to CFRP materials because of their non-corrosive nature, their exceptional durability in both alkaline and acidic environments, and their extremely low weight-to-strength ratio. After decades of research, experimental testing, and evaluation, CFRP materials are finally acknowledged as a viable alternative to steel reinforcement and steel prestressing strands. In Michigan, three highway bridges were built exclusively with CFRP reinforcement (2001, 2013, and 2014) [1] and four side-by-side box beam bridges were transversely post-tensioned with un-bonded CFRP strands (2012, 2013, and 2014)[2]. In Maine, CFRP strands were used in Penobscot Narrows Cable Stayed Bridge in 2007 [3] and in Kittery Overpass double T beam Highway Bridge in 2014. In Virginia, pre-tensioning CFRP strands were used to pretress a recently constructed I-girder highway bridge carrying Route 49 over Aaron Creek (2014). The current article sheds some light on the design and construction of these bridges. In addition, it highlights the major concerns and issues that need to be considered while deploying CFRP in bridge construction.

2. Challenges in design and construction

Several challenges arise with the design and construction of bridges with CFRP reinforcement. For instance, the flexural design of beams prestressed with CFRP strands requires a detailed strain compatibility analysis for the section. Due to the brittle nature of CFRP, the outermost layer of CFRP reinforcement is the most critical layer and its failure often marks the start of the progressive failure of the beam. Therefore, unlike steel reinforcement, the area of CFRP prestressing/reinforcement can’t be lumped at the center of gravity. While strain compatibility seems simple and straight forward when only one layer of reinforcement is present, it tends to be iterative and more complicated with the presence of multiple layers of prestressed and non-prestressed CFRP. Multiple strain-compatibility-based equations are proposed to address this issue and simplify the flexural design. Unfortunately, these equations add complexity to the design and often confuse designers who are not familiar with CFRP materials.

Shear design is another area of confusion not only for designers but also for scholars. In general, the shear behaviour is less understood than the flexural behaviour because it is contingent to multiple parameters related to both concrete and reinforcement. Several shear design methodologies and equations have been developed over time for beams with steel reinforcement to guard against yielding of stirrups. Nevertheless, beams with CFRP stirrups advance directly to concrete crushing in the web or in the top flange with no signs of yielding. Consequently, shear design provisions for beams with steel stirrups do not support those with CFRP stirrups [4].

Another important crucial aspect in design is the effect of thermal changes on the overall performance of elements with CFRP reinforcement. The coefficient of thermal expansion for CFRP is almost negligible compared to that of concrete. Therefore, the increase or decrease in temperature directly influences the performance of structures with CFRP reinforcement especially those prestressed or post-tensioned with CFRP strands. For instance, Fig. 1 shows the change of TPT force in Pembroke Bridge over M-39 due to seasonal temperature change from -20 to 37°c. Therefore, the designer shall consider the loss/gain in prestressing level due to thermal changes.

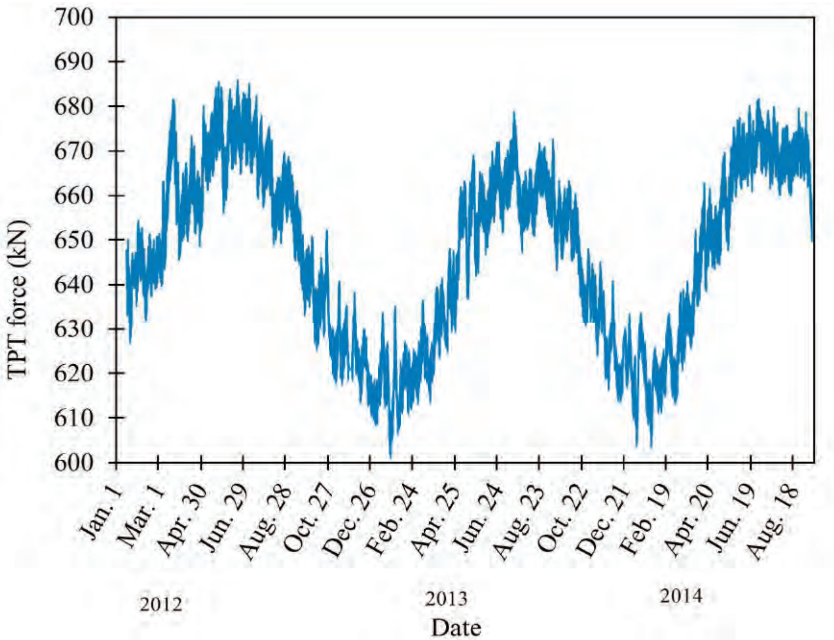

Fig. 1: Change in TPT force in Pembroke Bridge over M-39 due to seasonal temperature change

3. References

[1] GRACE N., NAVARRE F., NACEY R., BONUS W., and COLLAVINO L., "Design-Construction of Bridge Street Bridge-First CFRP Bridge in the United States", *PCI Journal*, Vol. 47, No. 5, 2002. pp. 20-35.

[2] GRACE N., JENSEN E., and BEBAWY M., "Optimal Transverse Post-tensioning Arrangement for Side-by-Side Box Beam Bridges", *PCI Journal*, Vol. 57, No. 2, 2012, pp. 48-63.

[3] ROHLEDER W., TANG B., DOE T., GRACE N., and BURGESS C., "Carbon Fiber-Reinforced Polymer Strand Application on Cable-Stayed Bridge, Penobscot Narrows, Maine", *Transportation Research Records Journal*, Issue No. 2050, 2008, pp.169–176.

[4] GRACE N., USHIJIMA K., ROUT S., and BEBAWY M., "Performance of CFRP Stirrups in Prestressed Decked Bulb T Beams", *ASCE Journal of Composites for Construction*, Vol. 120, No. 6, 2014, pp. 1720-1731.