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University Transportation Center Research Brief

Cross-Infrastructure Learnings for Alternative Bridge System Designs – A Case Study on the Hybrid Composite Bridge System

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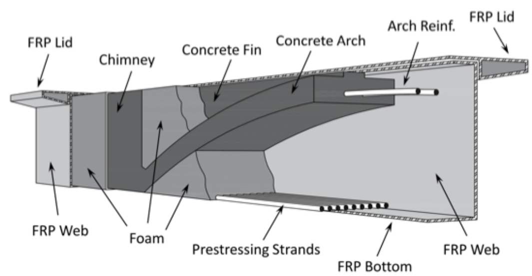
The hybrid composite beam (HCB) consists of a concrete tied arch encased in a fiber-reinforced polymer (FRP) shell. Compared to traditional materials, the HCB system is lighter in weight and has great potential as a sustainable design solution due to the protective FRP outer shell. The investigation presented herein was limited to the evaluation of the in-service performance of an in-service HCB bridge constructed in Virginia. The in-service evaluation provided critical information related to the overall system performance characteristics including lateral load distribution, dynamic load allowance and internal load sharing mechanisms inherent to the HCB design.

HCB System

The HCB system at its core can be described simplistically as a tied concrete arch encased in a FRP shell. A single beam consists of a parabolic concrete arch tied in the tension zone by steel, carbon fiber, or glass fiber prestressing strand. Under bending, the beam distributes loads from the top of the beam through axial compression of the arch down to the supports, where the tension strands restrain the supports. The entire arch system is contained within a glass fiber-reinforced polymer (FRP) box shell that protects the main load carrying components and contributes additional shear resistance.

For the FRP shell or box, a quad-weave fiber fabric is used to avoid custom alignment of fiber orientations for each application. During fabrication of the beam, several layers of the fiberglass fabric are laid in the box formwork. The tension zone reinforcement is laid in the base of the beam formwork and covered with a single additional fiberglass sheet prior to the resin infusion process. Options for the tension reinforcement include carbon fiber, glass fiber prestressing strands, as well as traditional steel strands and a welded steel wire mesh. While each is a valid option, steel remains the most cost effective. The core formwork, cut of polyisocyanurate foam, is laid in the mold next, filling the void space of the box while retaining the arch-shaped formwork for the concrete to be filled in the beam at a later time. The height of the voided concrete formwork varies parabolically over the length of the beam to create the arch shape.



Hybrid Composite Beam System

The shell is then infused with a vinyl ester resin through a closed-mold vacuum-assisted resin transfer method (VARTM), which upon infusion creates a composite unit of FRP, steel and foam. While the foam alone is not structurally significant, it does offer some lateral stability to the beam, improves the elastic buckling capacity of the FRP webs, aids in the development of the shear resistance through tension field action, and helps to distribute the load to the rest of the beam beneath the concrete arch.

The HCB FRP lid and wings are manufactured separately from the rest of the beam, but glued together prior to placement of the arch concrete. Prior to concrete placement, inclined shear connectors are inserted through holes drilled in the lid to enforce composite action between the HCB and a conventionally cast reinforced concrete deck. Once the shear connectors are in place, a highly workable concrete mixture, typically self-consolidating concrete (SCC) is fed into the beam to fill the voided conduits. The concrete is vibrated to ensure that all void spaces are filled entirely.

Purpose and Scope

The focus of this study was on the characterization of the in-service structural behavior of the HCB system in bridge application. The goal of the investigation was to use traditional live-load testing strategies to validate the design assumptions used in construction and correlated these assumptions with measured response. In particular, the study focused on characterizing the flexural lateral load distribution behavior, the element load sharing behavior, and the dynamic load amplification.

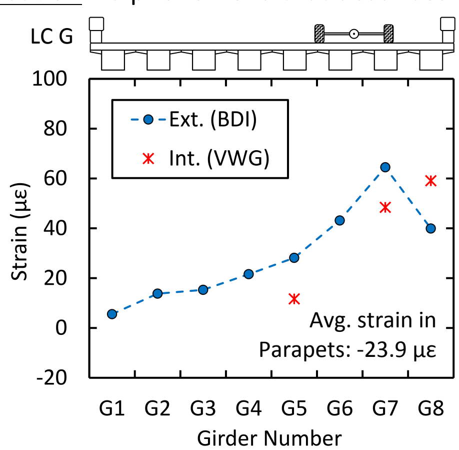
Experimental Program

To satisfy the testing program and establish a mechanism for monitoring, an extensive instrumentation plan was designed. Measurement of the desired behavior characteristics required a variety of sensors with multiple data acquisition systems. The load testing was performed using a series of highway load test vehicles, which were systematically traversed across the bridge to maximize loading response. The loading was performed in both quasi-static and dynamic configurations.

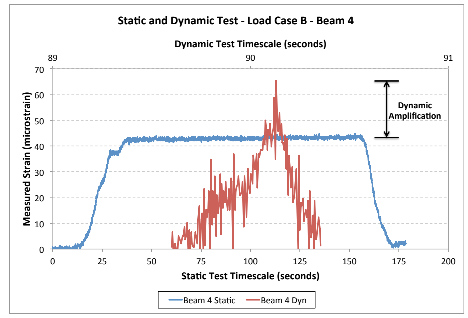
Results

Time-series measurement data was translated into description of system behavior characteristics:

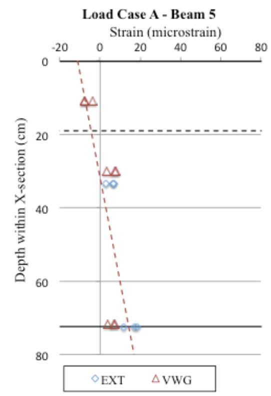
Lateral Load Distribution – a phenomena that describes the transverse load sharing behavior of a beam bridge system and a fractional measure of how much load is resisted by an individual member.



Dynamic Load Allowance – the amplification of load above that of the static loading that occurs during dynamic loading and is described as a function of the interaction of the bridge and vehicle dynamic response interaction and is influenced by properties such as mass, stiffness, vehicle speed, and surface roughness.



Internal/External Load Sharing Behavior – the relative load sharing behavior for the HCB system that describes the relative contribution of the internal (concrete arch and prestressing steel) and external (FRP shell) components.



Outcomes

The findings of the study may be summarized as follows:

Lateral load distribution behavior determined from the externally mounted strain gauges was consistent with expected trends. It is anticipated that if the HCB system is use in an unballasted track railroad application, this distribution would similar to that observed during the live load testing. However, if the system utilized a ballasted deck these findings would not necessarily hold, but it is anticipated that the distribution would likely be more uniform as the ballast would serve to distribute the load more uniformly amongst all of the beams.

Dynamic amplification was generally comparable to what would be expected for highway application, but at times exceeded the design threshold. For railroad applications, this dynamic response may be a challenge for this system due to the inherent flexibility in the system coupled with the higher impact design loads recommended by AREMA, relative to highway applications.

Load sharing behavior indicated that the FRP shell does not act compositely with the internal HCB components (concrete arch and prestressed strand tie). In fact, the arch may exhibit local flexural bending whereas slippage between the strand and FRP shell is a possibility within the tension zone.