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# Testing of a Prototype Hybrid-Composite Beam Span at FAST

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## Summary

Transportation Technology Center, Inc. (TTCI) is evaluating advanced materials and designs for use in railroad bridges. As part of this process, TTCI is testing a prototype hybrid composite beam (HCB) span at the Facility for Accelerated Service Testing (FAST). The experimental span has performed well under 95 million gross tons (MGT) of heavy axle load traffic to date.

- Testing to date shows no deterioration in span performance over the initial 95 MGT of service at FAST.
- Deck thickness and reinforcement are critical in order to prevent deck cracking. The current deck, with similar thickness and reinforcing as a comparable prestressed concrete span, is performing well.
- The HCB span is slightly deeper than a typical prestressed concrete span of the same length.
- Mid-span deflections of the HCB span under train traffic are about twice those of a comparable prestressed concrete span, but still within limits recommended by the American Railway Engineering and Maintenance of Way Association.
- Untested and unresolved concerns at this point include fire resistance and survivability in a lateral collision.

The HCB span uses concrete, steel, and fiberglass components. The HCB system consists of a concrete arch connected at its ends with steel tension wire, all encased in a fiberglass beam shell. The concrete arch resists compression, and the steel resists tension. The span has a reinforced concrete deck.

This revolutionary bridge technology offers several potential benefits to reduce bridge replacement costs: HCB spans with precast decks can be about 20 percent lighter than concrete spans of the same length. HCB spans with cast-in-place decks can offer considerably more reduction in handling weight for applications such as offset alignments where track time is not critical. The reduced weight might enable railroads to use HCB spans as a 3-for-1 or 4-for-1 replacement of timber spans, rather than the 2-for-1 that is typical using concrete spans. Longer spans might reduce the overall pile driving effort required, thus reducing both cost and track window needs. HCB spans might be more economical than some of the shorter steel spans currently used for railroad bridges.

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**INTRODUCTION**

Railroad bridge engineers are always looking for ways to make their limited budgets go a bit further. If new bridge spans could be purchased for less and installation could be less cumbersome, then more components of aging bridges could be replaced more efficiently.

The HCB span offers the potential for savings in both material and installation costs. The first railroad HCB span is currently undergoing evaluation testing at FAST.

Prices for bridge materials, particularly steel, have escalated tremendously in recent years,\* so the potential benefits of alternative bridge materials and technologies are becoming more attractive. Fifty years ago, prestressed concrete was a new technology for railroad bridges. It has now become a mainstay. Perhaps HCB technology has similar potential. The testing underway at FAST should help determine that.

**Performance Testing**

To date, the prototype HCB span installed at FAST has accumulated 95 MGT of traffic under the heavy axle load (HAL) train made up of 315,000-pound cars. Note that the test train at FAST typically runs at 40 mph and does not include cars that generate significant wheel impact loads.

This HCB span is 30 feet long. The original double cell prestressed concrete box girder span was removed to allow testing of the HCB span. Figure 1 shows the HCB test span at FAST.



Figure 1. Test Train at FAST on HCB Prototype Span

The HCB has performed satisfactorily in testing to date. No defects have been noted. No deterioration of performance has been measured. After 20 MGT of traffic, the track ballast was excavated at both ends and mid span to inspect the concrete deck. No cracks or other signs of deterioration were noted.

The ballast deck test span at FAST is installed in a 5-degree curve with 4 inches of superelevation. The deck of the span is level. There are 4 inches of additional ballast beneath the ties on the high rail side of the track. At the typical test train speed of 40 mph, the high rail is more heavily loaded than the low rail as the balance speed for this curve is about 34 mph.

\* U.S. Bureau of Labor Statistics

**Span Characteristics**

The span at FAST is comprised of eight HCB sections, covered with a concrete deck. The deck was cast in two halves, and the span was installed in the same way as a typical prestressed concrete span, as Figure 2 shows. Each HCB section is 28 inches deep by 20 inches wide. Overall width of the HCB span is similar to that of a typical double-cell prestressed concrete box girder span. The concrete deck is 6 inches thick, with reinforcement similar to that used in decks of typical double-cell prestressed concrete box girders. The overall height of the span is 34 inches, or 4-inches deeper than the concrete span it replaced. The deck includes integral ballast curbs to match those on the other spans in this bridge.



Figure 2. Installation of HCB Prototype Span at FAST

Lifting weight of the half-span sections with deck is about 10 to 20 percent lighter than a comparable prestressed concrete double-cell box girder section. For bridges constructed on an offset alignment where track time is not an issue, substantially more weight savings is possible by using a cast-in-place concrete deck. The HCB sections without the deck are much lighter. This lighter weight can result in substantially reduced costs for transportation, handling, and erection of HCB spans. It should also be possible to handle longer spans with existing cranes.

**Composition of a Hybrid Composite Beam**

The HCB is comprised of three main subcomponents: shell, compression reinforcement, and tension reinforcement. The shell is comprised of a fiber reinforced plastic box beam. The compression reinforcement consists of portland cement concrete that is pumped into a profiled conduit within the beam shell. The tension reinforcement consists of steel wires anchored at the ends of the compression reinforcement. Figure 3 shows the orientations of these subcomponents.

Prior to casting the concrete arches, shear connectors were inserted into holes predrilled in the top flange of the HCB that extend through the foam core on a 45-degree angle. The shear connectors were comprised of a 1/2-inch diameter coil rod with a hex nut screwed into the end embedded in the concrete

arch and an 8-inch, 90-degree bend that anchors into the composite deck slab on top of the beams.

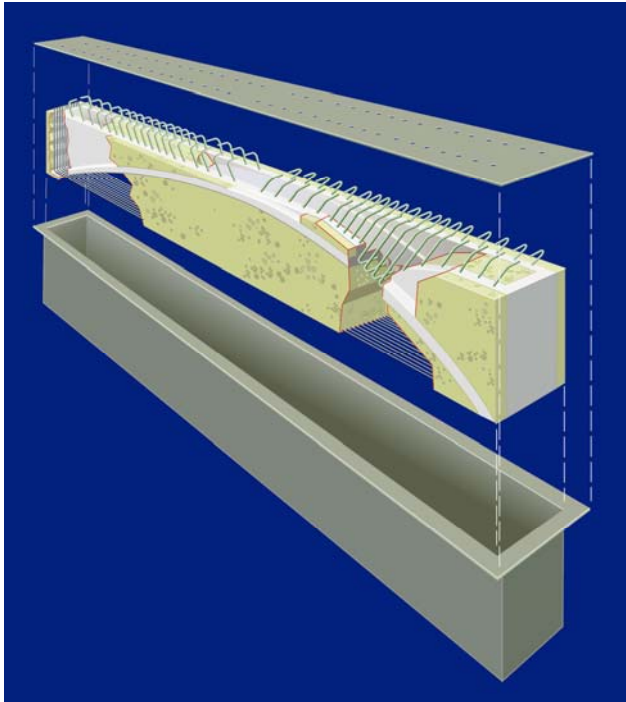


Figure 3. Schematic Drawing of Hybrid Composite Beam

A self-consolidating concrete (SCC) mix design was used as the compression reinforcement in the beams. This concrete was placed by pouring it into the chimneys at the ends of the beams and vibrating up the arches until they were nearly filled, and then filling in the remaining concrete at mid span on the beams. In more recent applications of the HCB, the SCC was simply pumped into the beam shells through attachments installed in the top flanges at the ends of the beams. This process can be completed in a matter of minutes.

Discussions with railroad bridge engineers indicate that some railroads design beams to meet deflection criteria without contribution from the bridge deck. In the case of this particular prototype HCB span, a composite contribution from the deck is needed to meet the deflection recommendation.

### Development of HCB Technology

The HCB technology has been in development for about a decade. Extensive laboratory testing was performed at the University of Delaware. Funding for much of the laboratory work was provided through the Transportation Research Board. Laboratory tests included both fatigue testing and tests to failure of individual beams. The bridge at FAST is the first full HCB span with multiple beams and a deck.

Before getting to the fabrication of the 30-foot prototype, extensive testing and manufacturing experiments were conducted on smaller scale beams 8-feet long to determine tooling, lay-up, and infusion techniques that could be scaled up for fabrication of larger beams.

### Deck is Critical

The initial 30-foot HCB prototype installed at FAST had a concrete deck only 4 inches thick, with only minimal steel reinforcement. After a series of controlled tests and tonnage accumulation, the track was removed for deck inspection. The inspection revealed cracks in the concrete deck at both ends of the span. The HCB sections themselves showed no signs of deterioration or damage. Further details and analysis of the initial testing at FAST, as well as strain and other measurement results, were presented at the 2008 AREMA Technical Conference (Hillman and Otter) in Salt Lake City, Utah.

In order to conduct endurance testing on the HCB span, the original deck was removed. A new and thicker 6-inch concrete deck was cast, with significantly more steel reinforcement. The new reinforcement pattern followed that used in the BNSF-Union Pacific joint common standard design for prestressed concrete double-cell box girders of the same length. This thicker deck, with heavier reinforcement, has performed satisfactorily through 95 MGT of HAL traffic at FAST.

### Span Measurements

As predicted, the HCB span deflection is similar to that which might be expected for a comparable reinforced concrete span. The HCB deflects about twice as much as a comparable prestressed concrete span. Figure 4 shows deflections measured after various amounts of traffic. Note that deflections increased with accumulated tonnage, as track geometry became rougher. After tamping, deflections decreased to previous amounts. This illustrates the importance of maintaining good track geometry on bridges and bridge approaches to prolong the life of bridges.

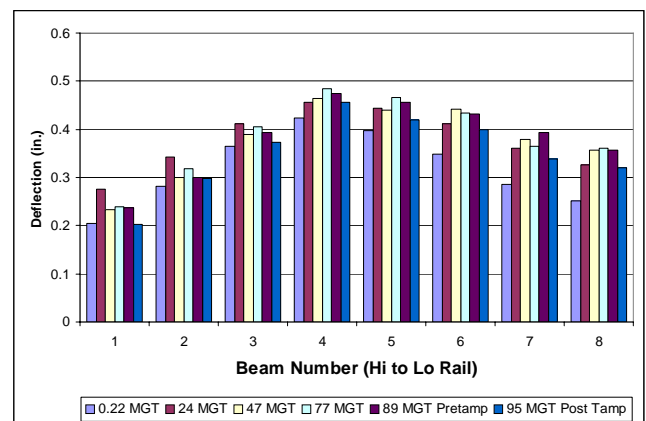


Figure 4. Deflections of HCB Prototype Span Beams under Test Train at FAST

Also note that the deflections are not uniform. The deflections near the outsides of the cross section are less than those near the center. This might be due to a stiffening effect from the ballast curbs on the outsides. While the curbs have asphalt plank inserts to reduce compressive stresses, the curbs

nonetheless add stiffness which reduces deflections in their vicinity. The ballast curb details are identical to those found in other (prestressed concrete) spans of the state-of-the-art concrete bridge at FAST, following a Union Pacific Railroad standard design.

Figure 5 shows the peak strains on the bottoms of the eight HCB sections at mid span under typical train operation at FAST. Note that the strains are not uniform. (No measurements were obtained for beam 2 due to a failed strain gage.) Nor do they correlate with the measured deflections. The strains might be affected more by bearing conditions for each beam. While care was taken during installation to evenly support all sections, there are variations. These hand-produced prototype beams are likely to have more variation than the plant-fabricated beams now being produced. Strain variations have previously been measured in prestressed concrete spans as well. The magnitudes of the strains indicate low stresses in the various components of the HCB, as predicted. Since the governing factor in design of this particular HCB was deflection, there is plenty of reserve load-carrying capacity.

In an effort to better understand the behavior of the HCB span under load, strain gages were applied to the side faces at various depths on the outside beams near mid span. The results are shown in Figure 6. As expected, the strains are largest at the bottom of the section. The strain profile is not as linear as might be expected in a steel beam, and the strains indicate that most of the HCB below the arch is in tension. The ballast curbs could have a significant influence as noted above regarding the deflections. The ballast curbs might be carrying a significant amount of compression on the outside beams, forcing most of the HCB to counter in tension. Unfortunately, only the outside beams were accessible for installing strain gages on side faces.

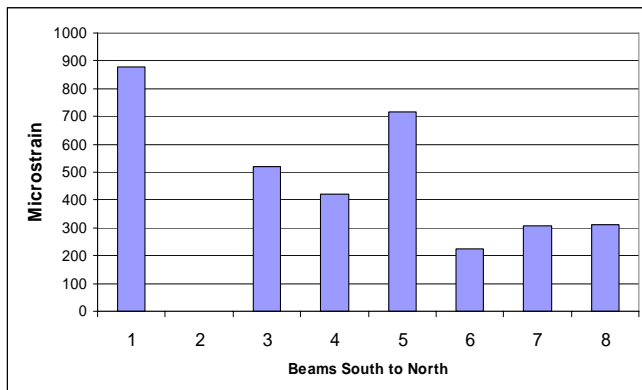


Figure 5. Strains of Prototype Span Beams under Test Train at FAST

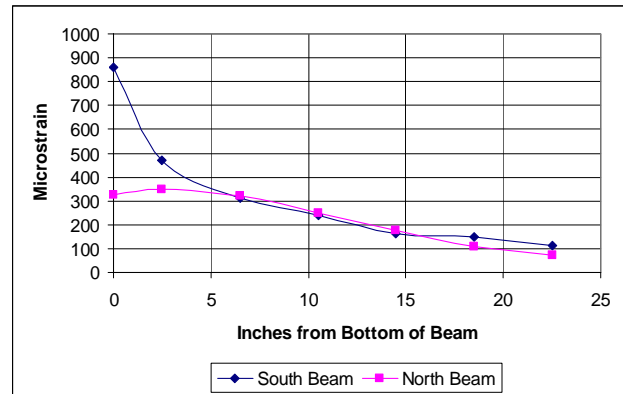


Figure 6. Strain Profiles of Outside HCB Span Beams under Test Train at FAST

**Future Testing, Potential Applications and Benefits**

Plans for future testing include longer spans. For railroad loadings, HCB spans in the 50- to 60-foot range seem feasible. This is a length range where the HCB could compete with steel alternatives.

The possibility of longer spans and reduced construction expense might also make HCB spans an economical alternative for replacement of timber spans.

Shipping and erection of HCBs will vary depending on the application. For example, in new track construction or on an offset alignment, it would often be desirable to cast the concrete deck in place. In some cases, it might even be advantageous to cast the arch concrete in place or at the jobsite. Construction time is generally less critical for such bridges resulting in ample time to cast and cure concrete on the site. As a result, the shipping and erection weight of the HCB beam shells would be approximately 1/3 that of a steel beam or 1/10 the weight of a similar concrete beam. This results in a significant cost savings, as multiple beams can be shipped more economically, and the beams can be erected with smaller cranes than would be necessary for a purely precast concrete bridge.

For railroad bridges replaced under traffic, however, it may be more desirable to erect the bridge in place with concrete arches, deck, and ballast curb already cast, as was done at FAST. Although this scenario does not provide for the maximum benefit of the lightweight nature of the HCB, it does help expedite erection while minimizing disruption to train operations.

As reported, some of the benefits of the HCB include lighter weight for reduced erection time and cost, optimization of materials used, excellent corrosion resistance leading to lower life-cycle costs, and simplicity in design, fabrication, and erection. With ongoing refinements and validation testing, the HCB span offers a bridge technology that is potentially competitive with conventional methods of construction. Untested and unresolved concerns at this point include fire resistance and survivability in a lateral collision.

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