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First CFRP Bridge in the USA Michigan Researchers and Consultants Using Tomorrow's Technology Today

The need for longer lasting and more durable bridges is leading researchers to look at new materials and construction methods. While other states are still theorizing about the application of corrosion resistant, durable materials such as carbon fiber, one bridge in Michigan is testing these new materials. The first bridge in the USA to use carbon fiber reinforcement as the primary reinforcing material spans the Rouge River in Southfield, Michigan.

Background

The prevalent bridge construction material is steel-reinforced concrete. The very different benefits of very different materials, steel and concrete, form durable and long-lasting structures. Concrete lends compressive strength to a structure while resisting deterioration by environmental influences such as freezing, erosion, and chemicals. Steel contributes tensile, or pulling, strength to a structure, but is much more susceptible to the environment. The environment begins to take it's toll on steel as soon as it is manufactured, and when it's set in concrete and becomes exposed to road salt and water, it corrodes quickly, leading to loss of material and loss of strength. Existing solutions to the problem of corroding steel-reinforced concrete structures include epoxy coating the steel, increased concrete cover,

and replacing black steel with stainless or non-steel reinforcement.

If reinforced concrete structures are protected from corrosion, either by using non-corroding materials or protecting metal from corrosion, bridge life expectancies could surpass 70-80 years, doubling or tripling life expectancies of current designs. The extended life expectancies not only save on construction and material costs, but also reduce lane closures and congestion due to construction. Researchers are therefore looking to apply new materials to replace or supplement carbon steel reinforcement in bridges. One group of researchers at Lawrence Tech University (LTU), with research funding from the National Science Foundation, worked extensively with Hubbell, Roth & Clark, Inc. (HRC) and the City of Southfield to design and build a bridge that completely replaces black steel reinforcement with carbon fiber and stainless steel members (Figure 1). The carbon fiber and stainless steel reinforcement provide for a strong and corrosion-resistant bridge.

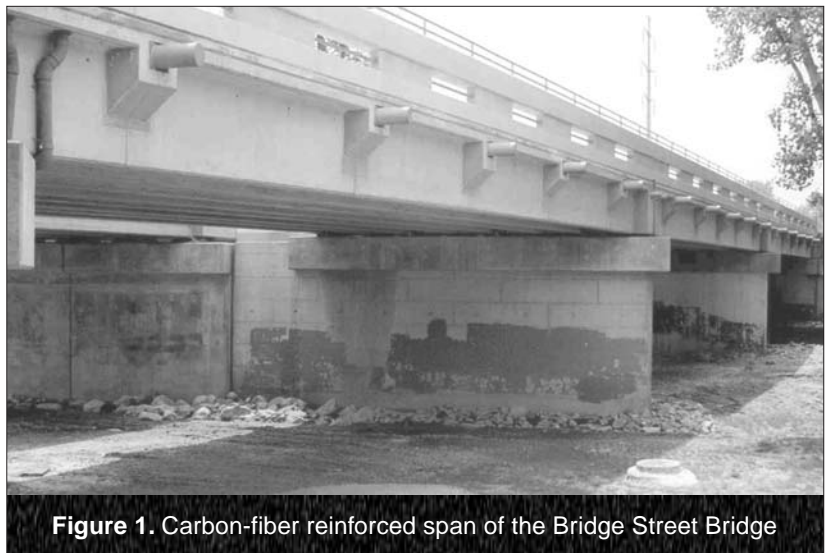
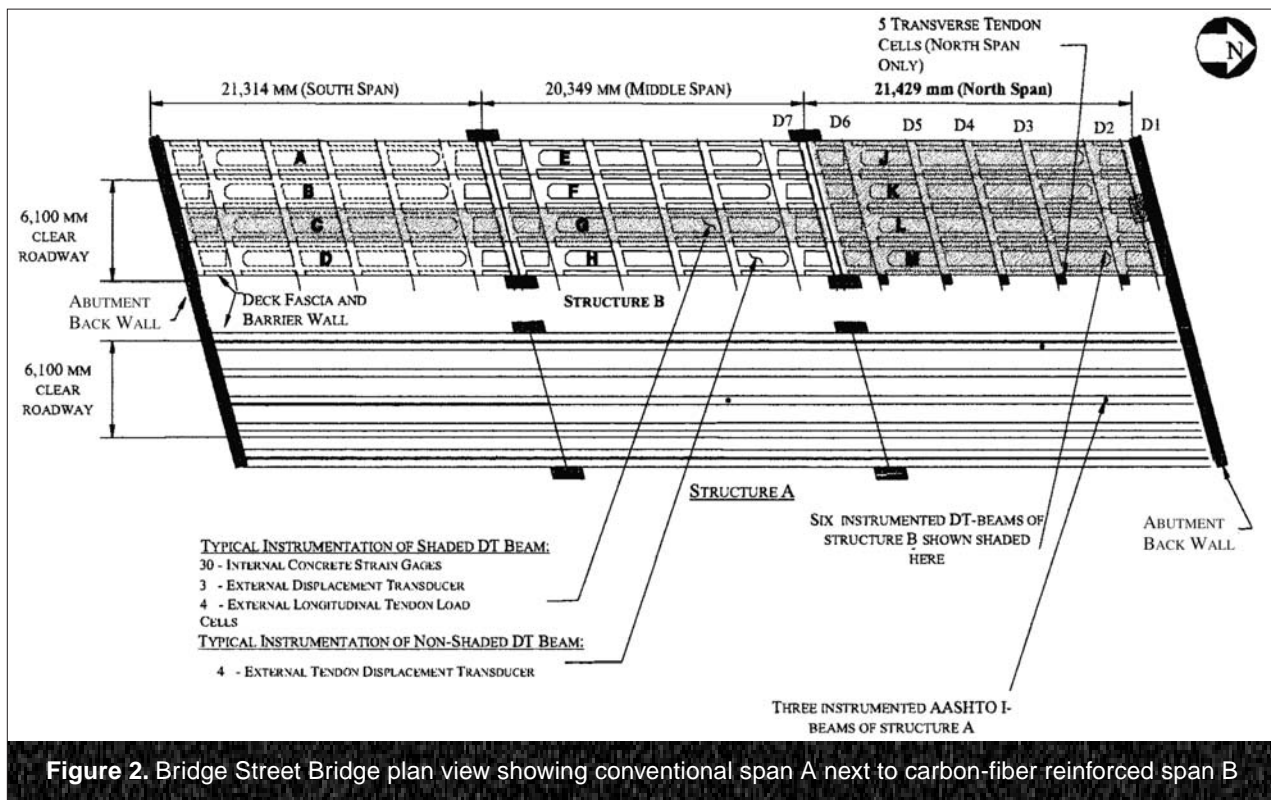


Figure 1. Carbon-fiber reinforced span of the Bridge Street Bridge



The primary shortcomings of carbon fiber reinforcement are its cost and low ductility. A carbon fiber reinforced bridge would be less ductile than a steel-reinforced bridge with a similar ultimate load, posing a risk of complete failure should overloading occur. LTU's tests showed that their pre- and post-tensioned bridge beams are reasonably ductile, addressing the primary shortcoming of carbon fiber reinforcement. The other shortcoming, cost, becomes less significant as carbon fiber materials become more widely used in structures. The longer life expectancy of carbon fiber-reinforced bridges also reduces the costs of repair, reconstruction, and safety, making the total lifetime cost of a production carbon fiber-reinforced bridge comparable to traditional bridges that require more maintenance.

Bridge Design and Testing

The design and construction of the Bridge Street Bridge followed extensive testing and cooperation between academic, government, and commercial organizations. The

bridge team built and tested a full-scale beam, loading it to failure to evaluate the ability of these beams to address questions of ductility. Once the design was proven through laboratory testing, the bridge was constructed with one side using conventional girders, and the other side using special carbon fiber reinforced beams to make a side-by-side comparison. The bridge design includes monitoring systems to evaluate bridge performance under real service loads for five years.

The carbon-reinforced bridge section consists of four modified double-T girders with a minimum 75 mm thick deck slab (Figure 2). LTU and HRC designed the precast, prestressed double-T bridge

beams to be reinforced with carbon fiber. Straight and bent carbon fiber bars are used for the non-tensioned reinforcement and stainless steel is used for the stirrups. The entire reinforcing cage is assembled similarly to traditional steel cages (Figure 3). The pre-tension carbon fiber strands are also used in a manner similar to steel pre-tensioning



strands in concrete beams. Post-tensioning carbon-fiber strands are draped underneath the bridge between the beam webs (Figure 4).

Girder Design

The double-T beams are similar in design to conventional steel-reinforced beams. Instead of steel bars and tendons, each web is reinforced with 10 rows of three 10 mm bonded prestressing carbon fiber reinforced polymer (CFRP) tendons; six rows of two 12.5 mm non-prestressing carbon fiber composite cable (CFCC) strands; and one row of three 12.5 mm non-prestressing CFCC strands in each web (Figure 5). Two layers of 10 mm CFRP rods and a carbon fiber mesh reinforce the flange. To complement the non-corroding carbon-fiber reinforcement, stainless steel stirrups complete the internal beam reinforcement.

External longitudinal and internal transverse unbonded CFCC strands supply post-tensioning reinforcement. Longitudinal 40 mm CFCC post-tensioning strands are externally draped between diaphragms D2 and D6, supplying longitudinal reinforcement. Before transport, technicians apply 60% of the final post-tensioning force to the longitudinal strands. After installation at the bridge site, 40 mm and 21.8 mm CFCC strands are inserted through all four double-T girders to provide transverse post-tensioning reinforcement.



Figure 4. Externally-draped post-tensioning strands

All of the carbon-fiber reinforced girders were formed in a single pan form at a Windsor, Ontario plant. The spans are 20.349 m, 21.314 m, and 21.429 m long. The designers specified concrete with 28-day 52 MPa design strength for the girders and 38 MPa concrete for the composite topping.

Girder Testing

The testing began with construction of a beam identical to the beams intended for service on the bridge. The test beam was constructed in Windsor, Ontario and transported to Skokie, Illinois for testing. Instrumentation of the test beam is similar to the service beams and was designed for long-term monitoring. Researchers set up the test by loading a simply-supported test beam using hydraulic jacks. Throughout the test, computers collected load and displacement data from load cells and strain gauges installed on the beam.

Ultimate flexural strength was tested by incrementally loading the beam to 1304 kN and then unloading. The beam was then loaded again, this time to 2443 kN, where flexural failure occurred. The average beam deflection at midspan was 342 mm. Upon failure, all sixty prestressing strands failed while the post-tensioning strands did not. At ultimate load, the post-tensioning strands were within 60% of their tensile capacity. The ultimate load was 5.3 times the service load. Cracking load was

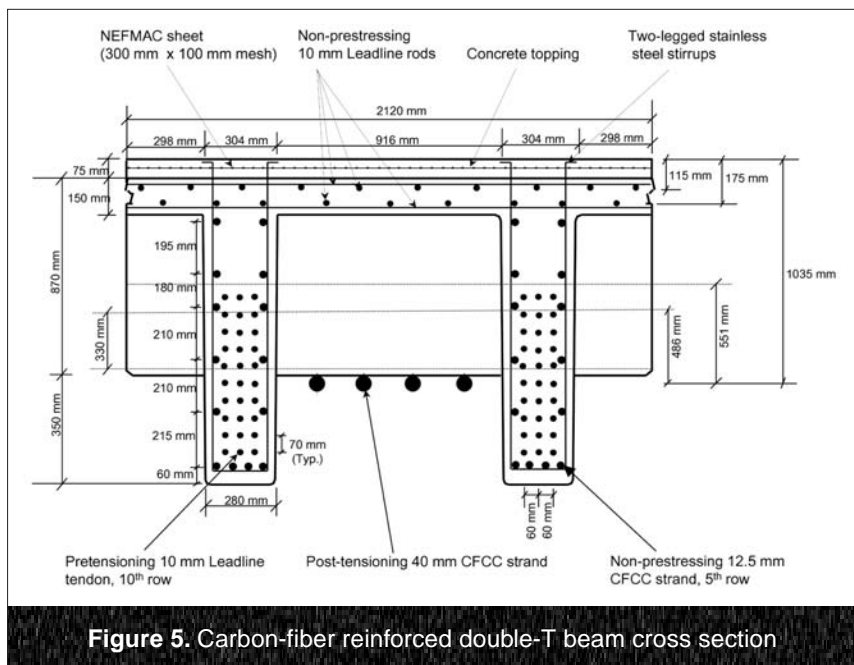


Figure 5. Carbon-fiber reinforced double-T beam cross section



Figure 6. Full-scale test of carbon-fiber reinforced double-T beam loaded to failure

1.4 times the service load. Researchers observed significant cracking before failure load was reached, which gives the desired indicator of possible failure before it occurs (Figure 6). The beam test results supported design expectations, allowing bridge construction to commence.

Bridge Construction

The girders were manufactured in Windsor and had to be transported by barge across the Detroit River. The transport company then transferred the twelve beams by truck to the bridge site. Two cranes at each end of the bridge first placed the four middle-span beams on existing piers, and then independently placed the four girders at each end span.

Once in place, workers installed the transverse post-tensioning strands and tensioned them in two stages. Following the first tensioning stage, the composite deck slab was placed, and then the final post-tensioning forces were applied to both the transverse and longitudinal strands. The final transverse post-tension force is 605 kN in diaphragms D2 through D6 and 175 kN in diaphragms D1 and D7. The longitudinal strands were tensioned to 457 kN in the final stage. Following final tensioning, workers constructed the sidewalk and barrier railing and applied a latex-modified surface mixture to the deck.

The bridges are heavily instrumented to monitor the long-term performance of the original design.

Both sides were instrumented to compare side-by-side performance of a conventional and unique design. The carbon-fiber reinforced bridge instrumentation measures pretension load, concrete strain in the cross section, girder camber and deflection, post-tension forces, external strand integrity, and strain of transverse and longitudinal external strands.

Conclusions

The Bridge Street Bridge uses novel materials and construction methods with the goal of finding bridge designs for the future. The LTU laboratory tests

and full-scale testing support the designers' expectations, showing how carbon fiber's expected shortcomings can be overcome. The bridge is already open for traffic and is demonstrating how carbon fiber can be successfully integrated into the nation's transportation infrastructure, giving planners and travelers long-lasting alternatives to traditional construction methods.

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Research Writer/Editor John Velat