Project Summary Report 1776-S
Development of Methods to Strengthen Existing Structures with Composites
Authors: Sergio F. Breña, Sharon L. Wood, and Michael E. Kreger
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PROJECT SUMMARY REPORT

Using Carbon Fiber Composites to Increase the Flexural Capacity of Reinforced Concrete Bridges

As traffic volumes continue to grow and legal vehicle weights increase, a need is emerging for the development of economic and efficient methods for strengthening the large inventory of older bridges in Texas. The majority of the bridges in the Farm to Market road system were constructed using reinforced concrete superstructures. A recent inventory identified approximately 2,700 reinforced concrete slab bridges and nearly 4,000 reinforced concrete pan girder bridges throughout the state. Many of these bridges were constructed in the 1940s and '50s.

Two factors motivate the desire to strengthen these bridges: bridges with an inventory rating less than HS-20 must be inspected annually, whereas the required inspection frequency for bridges with an inventory rating above HS-20 is every two years; and bridges with an inventory rating less than HS-20 cannot be widened, and therefore, must be replaced if the deck is too narrow to accommodate current traffic demands. Clearly the inspection and widening costs would be reduced if economic methods for strengthening existing reinforced concrete bridges were developed. Composite materials were viewed as being particularly attractive for this application because the increase in the dead load is small and the composite materials can be installed rapidly with modest interruptions to normal traffic patterns.

Most of the older reinforced concrete bridges in Texas were constructed using standard designs with slab or pan-girder configurations. These bridges tend to have short spans (20 to 40 ft), and the load rating is typically governed by flexural considerations. Therefore, the research project focused on increasing the flexural capacity of these standard bridges using commercially available carbon fiber reinforced composite (CFRP) materials. All bridges considered in this investigation were simply supported.

What We Did...

The research project was divided into three phases. During the first phase, a series of twenty-two, small-scale reinforced concrete beams were tested monotonically to failure. Four types of composite materials were used in this phase of the project. Two of the beams were used as control specimens to provide a basis of comparison, and twenty beams were strengthened using the CFRP composites. Eighteen of these beams were tested in the laboratory shortly after the composite materials were attached to the surface of the concrete. Two beams were moved outside after the composites were attached and were subjected to wetting and drying cycles for nine months before they were tested. The composites for these two beams were covered using the materials recommended by the manufacturers for UV protection. In addition, one of these beams was subjected to a sustained load equal to approximately 20% of the load corresponding to yielding of the reinforcement.

The primary experimental parameter during the first phase of the research project was the layout of the CFRP materials. Longitudinal composite materials were attached to the tension fiber of the cross section in the initial series of tests. Because the composite materials debonded prematurely from the surface of the concrete, additional configurations were tested. Longitudinal composite materials were attached to the sides of the cross section and transverse straps were added along the length of the beam. The influence of the transverse straps on the shear strength of the beams was not investigated.

During the second phase of the project, eight small-scale reinforced concrete beams were subjected to fatigue loads. The amplitude of the applied loads and the number of cycles were the primary experimental variables in this phase of the project. Five of the specimens were subjected to load reversals in which the maximum load did not exceed 50% of the yield load for the original reinforced concrete beam. These specimens were cycled either 10,000 or 1,000,000 times and then subjected to monotonically increasing loads. Three of the specimens were subjected to extremely large load variations in which the maximum load exceeded 90% of the yield load of the original reinforced concrete beam. These specimens failed in fatigue. Two of the composite materials that were tested in the first phase were used in the second phase of the project, and transverse straps were used for all beams.

Full-scale sections of bridges were tested during the third phase of the project. Two prototype bridges were selected for study: a 30-ft, pan-girder bridge that was constructed in 1951, and a 25-ft, FS-slab bridge that was constructed in 1945. Both prototype bridges were two lanes wide and were designed to carry two H-10 trucks. Two pan-girder specimens and two slab specimens were tested. Each pair of test specimens was nominally identical, but different composite materials were used to strengthen the individual specimens.

The test specimen based on the pan-girder bridge included two girders. Because the bottom surface of the girders is not smooth due to the presence of a joint in the forms, the longitudinal composites were not attached to the bottom surface of the joists along the centerline of the member. The configurations tested eliminated the need to grind the bottom surface of the girders and dramatically reduced the time needed to install the composite materials. Transverse straps were used along the span. The inventory load rating for the prototype bridge was HS-12.2 for flexure. The amount and distribution of the composite materials were selected to increase the inventory rating to HS-20.

The test specimen based on the FS-slab bridge included only a 6-ft wide portion of slab. The structural curbs were not included because the most common concern with FS-slab bridges is the width, and the curbs must be removed in order to widen the deck. Without the structural curbs, the inventory rating for the prototype slab was HS-6.0. The amount and distribution of composite materials were selected to increase the inventory rating for the slab to H-10, which corresponded to the original design strength of the entire bridge.

In order to reproduce conditions in the field, the full-scale test specimens were cracked before the composite materials were attached and the specimens supported their self weight. Therefore, the composites only contributed to the ability of the specimens to resist live load. All four specimens were subjected to monotonically increasing loads.

What We Found…

Static Tests of Rectangular Beams

- The most common mode of failure was debonding of the longitudinal CFRP materials from the surface of the concrete. Transverse straps helped to delay the onset of debonding, and three of the beams with transverse straps failed when the longitudinal composite materials ruptured.
- While the strength of most of the specimens with CFRP exceeded the capacity of the original reinforced concrete beams, the displacement capacity was approximately half the displacement capacity of the unstrengthened beams.
- The presence of flexural cracks influenced the response of the strengthened specimens. Debonding of the longitudinal CFRP materials tended to start at the location of flexural cracks within the shear span. In some cases, small vertical movements across a crack tended to pry the CFRP materials from the surface of the concrete.
- Because the CFRP materials debonded from the concrete, the typical assumption that strains vary linearly with depth is not valid after the longitudinal reinforcement yields. The measured strains in the CFRP materials at capacity were considerably less than would be

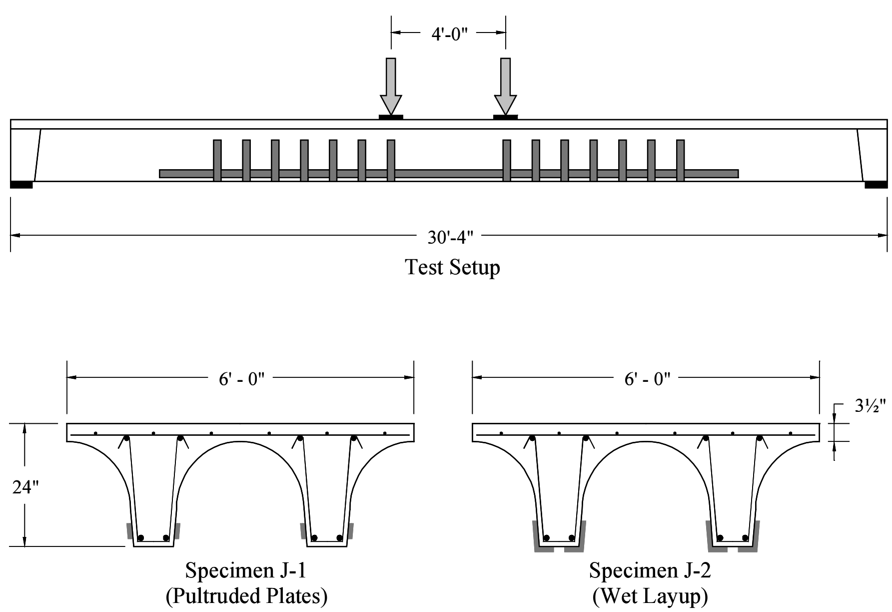

Figure 1 Full-Scale Pan-Girder Test Specimens

calculated using a linear variation with depth. In most cases, the measured strains in the CFRP materials at capacity were approximately half the rupture strain reported by the manufacturers.

Long-Term Exposure Tests

- The long-term wetting and drying cycles had essentially no influence on the response of the strengthened beams.
- Sustained gravity loads also had essentially no influence on the response of the strengthened beams.
- The UV protection system appeared to be appropriate because there was no indication of degradation of the composites after being exposed to the environment for nine months.

Fatigue Tests

- The strength of the strengthened test specimens was not influenced by up to 1,000,000 cycles with a maximum load of approximately 50% of the yield load of the original reinforced concrete specimen. The beams that were subjected to fatigue loads were slightly more flexible than the beams that were subjected to monotonically increasing loads. Because expected live loads are in this range, the influence of fatigue loading appears to be minor.
- Both of the strengthened specimens that were subjected to repeated cycles with a maximum load of approximately 90% of the yield load of the original reinforced concrete specimen failed by debonding of the longitudinal composites.
- The fatigue response of the strengthened specimen that was subjected to repeated cycles with a maximum load of approximately 110% of the yield load of the original reinforced concrete specimen was limited by the fatigue performance of the longitudinal reinforcement.

Full-Scale Test Specimens

- Using longitudinal CFRP materials and transverse straps, it was possible to increase the flexural capacity of typical reinforced concrete bridges in Texas using commercially available materials.
- Although the measured strains did not vary linearly with depth, it is reasonable to use this assumption during design. However, the calculated strain in the composite materials should not exceed 0.007, regardless of the reported rupture strain of the material.
- For loads below yield of the longitudinal reinforcement, the CFRP materials carried less than 15% of the applied loads. After the longitudinal reinforcement yielded, the CFRP materials carried up to 30% of the applied loads.

The Researchers Recommend...

Based on the results of this investigation, CFRP materials appear to be a viable means of increasing the flexural capacity, and the inventory rating, of existing reinforced concrete bridges. The longitudinal composites should extend the entire length of the span and transverse straps should be provided. For pan-girder bridges, the spacing of the straps should not exceed the depth of the member divided by 2 and the straps should extend at least 4 in. above mid-depth of the cross section.

The scope of the research project was limited to reinforced concrete members that exhibited no evidence of deterioration or damage. Therefore, extreme caution should be used before applying the techniques described in this report to repair structural damage or to increase the flexural capacity of bridges with obvious signs of corrosion or other indications of material deterioration.

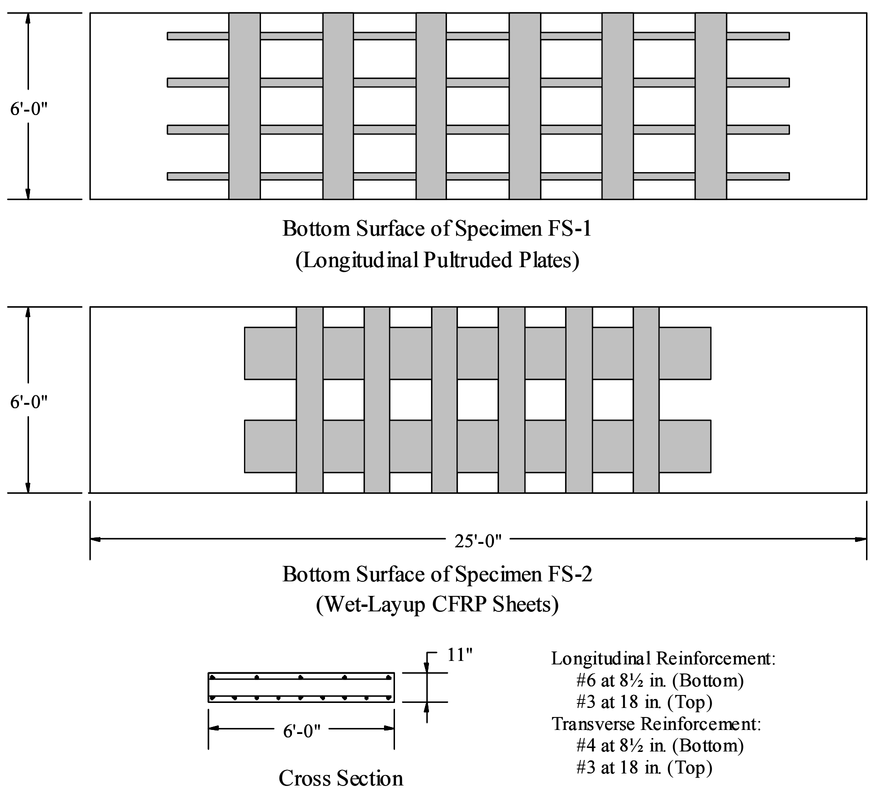

Figure 2 Full-Scale Flat-Slab Test Specimens

For More Details...

Research Supervisors: Michael E. Kreger, P.E., (512) 471-4579, kreger@uts.cc.utexas.edu
Sharon L. Wood, P.E., (512) 471-7298, swood@mail.utexas.edu

TxDOT Project Director: Mark A. Steves, P.E., (512) 416-2265, msteves@dot.state.tx.us

The research is documented in the following reports:

Research Report 1776-1, *Use of Carbon Fiber Reinforced Polymer Composites to Increase the Flexural Capacity of Reinforced Concrete Beams*, April 2001.

Research Report 1776-2, *Increasing the Flexural Capacity of Typical Reinforced Concrete Bridges in Texas Using Carbon Fiber Reinforced Polymers*, May 2001.

To obtain copies of the above reports, contact the Center for Transportation Research, The University of Texas at Austin, (512) 232-3126, ctrlib@uts.cc.utexas.edu.

TxDOT Implementation Status
January 2002

The results from this project will be implemented by the TxDOT Bridge Division on a case-by-case basis where an existing structure would benefit from strengthening, and when FRP strengthening is appropriate for that particular structure. The existing pan-form structure on FM 1362 over Sue Creek in the Bryan District has been strengthened using the results from this research project during scheduled rehab/widening.

For more information please contact Tom Yarbrough, P.E., RTI Research Engineer, at (512) 465-7685 or email at tyarbro@dot.state.tx.us.

Your Involvement Is Welcome!

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Center for Transportation Research
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The University of Texas at Austin
Center for Transportion Research
3208 Red River, Suite #200
Austin, TX 78705-2650