Michigan Department of Transportation
RESEARCH Administration

RESEARCH SPOTLIGHT

Project Information

REPORT NAME: Evaluating Long-Term Capacity and Ductility of Carbon Fiber Reinforced Polymer Prestressing and Post-Tensioning Strands Subject to Long-Term Losses, Creep and Environmental Factors, and Development of CFRP Prestressing Specifications for the Design of Highway Bridges

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Extensive testing of carbon polymer for highway bridge reinforcement provides guidance for improved designs

Since 2001, MDOT has successfully used carbon fiber reinforced polymer (CFRP) in place of steel as a prestressing and reinforcement material in the design and construction of several bridges across the state. CFRP components have tensile strength similar to steel, and their resistance to corrosion means they are anticipated to require less maintenance over time. Now, after four years of extensive research, MDOT's bridge designers have the technical information and specifications they need to predict how CFRP components will perform under a variety of conditions – and the design tools for future bridge projects.

PROBLEM

Steel has historically been the go-to material for reinforcing and pretensioning concrete used in highway bridge designs. While steel adds much-needed strength, it is prone to corrosion as extreme temperatures, water and deicing chemicals assault the bridge's structure, causing the steel reinforcement to deteriorate over time. Preventing corrosion and repairing damaged areas requires additional maintenance time and resources.

Concrete beams prestressed with CFRP strands were subjected to fire/loading tests to evaluate their fire endurance.

Years ago, MDOT engineers helped pioneer an innovative alternative: using CFRP in place of steel reinforcement in critical applications, such as mild reinforcing for bridge decks and concrete superstructure prestressing. CFRP prestressing strands are strong, corrosion-resistant and highly durable, making the material particularly well suited for bridges. In 2001, MDOT partnered with Lawrence Technological University

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> *"This research allowed us to test every question we had about CFRP and get good data so that we can continue to design bridges that are as safe and durable as normal steel bridges, but without steel's corrosive limitations."*
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> **Matthew Chynoweth, P.E.**
> Project Manager

in the design and construction of the first bridge in Michigan to use CFRP components. Several more have been constructed in the state in recent years.

CFRP bridge elements have performed well in the field, but the long-term durability of CFRP has not been fully understood due to its relatively new application in transportation infrastructure. Also, with the expectation that CFRP would be used even more frequently in future bridge designs, engineers expressed a need for production-friendly specifications for CFRP to optimize the design process and encourage more widespread use of the material.

RESEARCH

Through a research partnership between MDOT and Lawrence Technological University, a variety of experiments were conducted to evaluate the short- and long-term performance of bonded and unbonded prestressed CFRP strands. They also examined samples of scaled-down pretensioned T-beams (a combination bridge deck and I-beam) under various loading and environmental scenarios. Over the course of four years, the CFRP samples were subjected to 300 freeze-thaw cycles as well as combined fire/loading events and were exposed to severe weather conditions. These and other tests allowed investigators to calculate maximum tensile strength, guaranteed strength, environmental reduction factors, relaxation, creep rupture strength, short- and long-term prestress loss, and performance at high temperatures.

RESULTS

The data gathered through this research confirm what proponents of CFRP have long theorized about its long-term performance. Investigators found that subjecting the CFRP strands to both natural and controlled environmental conditions like moisture, rain, freezing rain, and extreme changes in daily and seasonal temperature did not significantly affect the material's strength or mechanical properties over time.

In addition, test results showed that some currently accepted parameters for CFRP are conservative and can be updated using this new data. For example, the guaranteed tensile strength for CFRP as recommended by the manufacturer can be significantly increased for design purposes. The findings also suggest that guide specifications recently developed by the American Association of State Highway and Transportation Officials (AASHTO) related to CFRP could likewise be recalibrated given the material's performance.

The research resulted in design criteria, design guidelines and recommendations to help make MDOT's design and construction of highway bridges using CFRP components more efficient. Additionally, researchers prepared four design examples using Mathcad software that can serve as a valuable design tool and reference for bridge designers.

For ease of use, the design guidelines are modeled after AASHTO's Load and Resistance Factor Design Bridge Design Specifications.

IMPLEMENTATION

The guidelines and detailed design examples developed from this research are already providing value to MDOT engineers. For instance, after calibration and testing, the Mathcad calculations were used in 2017 in the design of an I-75 bridge in Metro Detroit.

Armed with previously unavailable empirical data about the performance of CFRP, MDOT engineers can continue to design and construct corrosion-resistant highway bridges that are structurally reliable. With this material, MDOT's goal of building a bridge with a minimum 100-year service life is even closer to becoming a reality.

Research Administration

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This final report is available online at
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