Fiber-Reinforced-Polymer Reinforced and Prestressed Concrete

A new, but no longer emerging, technology

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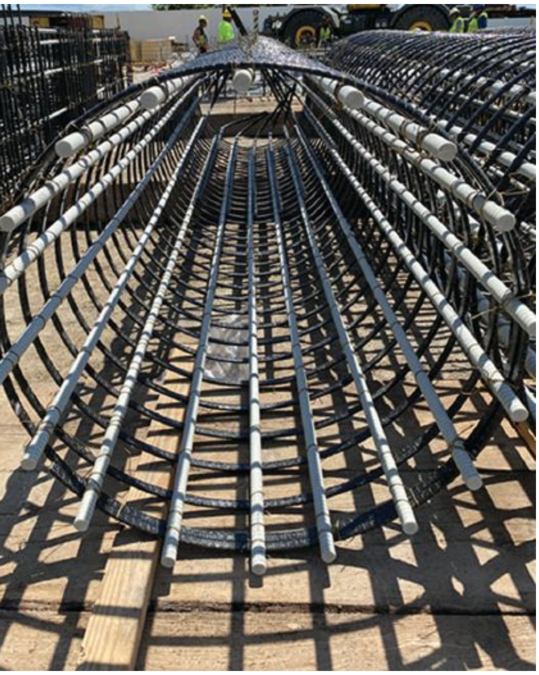
When it opens to the public in late 2023, the Harkers Island Bridge in Carteret County, N.C., will be the premier example of a prestressed concrete structure reinforced exclusively with fiber-reinforced-polymer (FRP) reinforcement. (See the Project article in this issue of *ASPIRE*®). The 3200-ft-long, 28-span bridge, which is currently under construction, will use only two types of composite FRP reinforcement for the piles, caps, columns, girders, and deck. Internal steel reinforcement was replaced in favor of glass-fiber-reinforced-polymer (GFRP) and carbon-fiber-reinforced-polymer (CFRP) composite reinforcements to create a bridge that will withstand the harsh saltwater environment with little maintenance over a design life of at least 75 years. Because there is no internal steel to corrode and the GFRP and CFRP internal reinforcements are not sensitive to chlorides, common degradation mechanisms are eliminated.

Glass-fiber-reinforced-polymer (GFRP) reinforcement cage for a cast-in-place concrete pier column. Bends in GFRP must be formed during manufacturing; GFRP cannot be bent on site. All Photos: North Carolina State University.



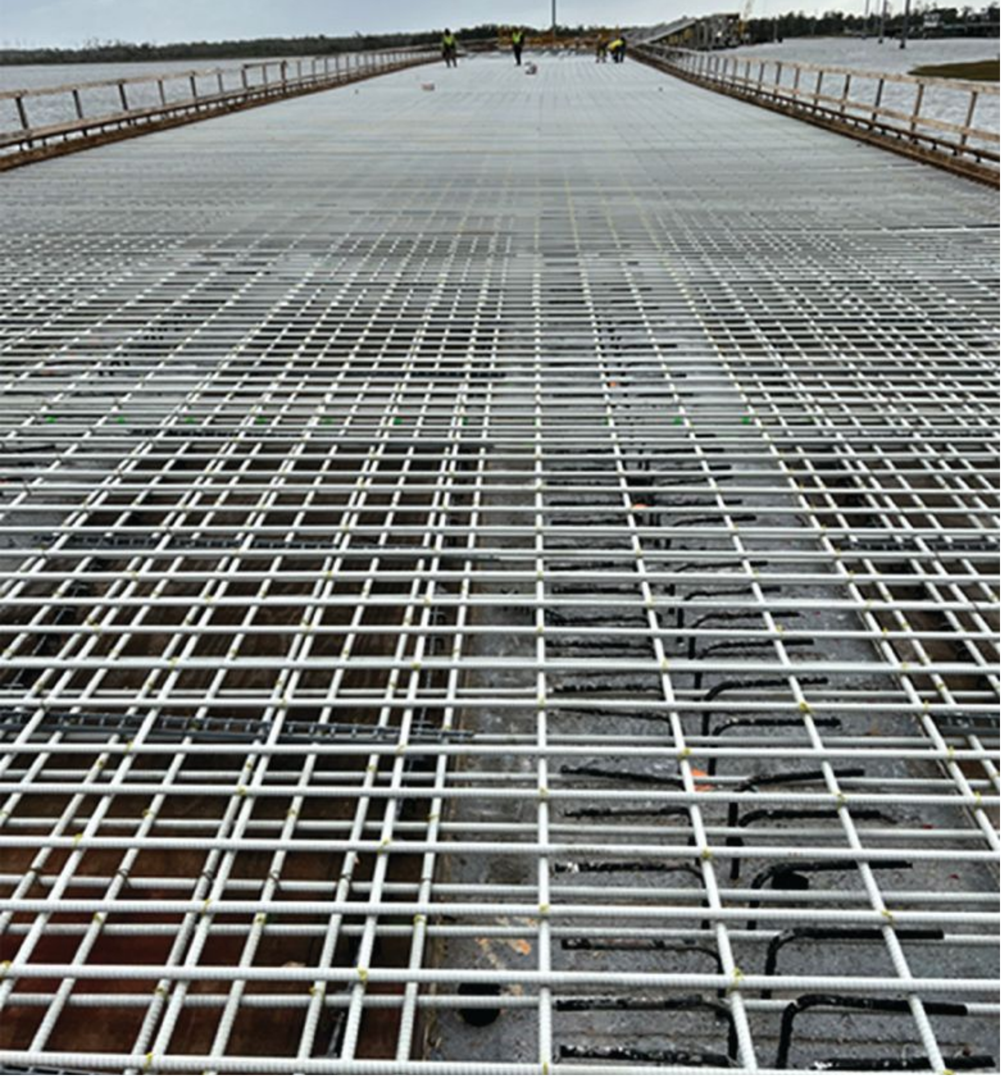
The current route serving Harkers Island consists of two prestressed concrete bridges joined by a small island. Both structures are just over 50 years old, but constant exposure to saltwater, including spray and splash onto the low-lying superstructures, has taken a toll on the internal steel reinforcement, and signs of corrosion are omnipresent. As the only link between Harkers Island and the mainland, it is especially important for the new bridge to be a reliable and durable piece of infrastructure on which the community can depend. The use of internal FRP reinforcement in the new bridge will help ensure that the bridge remains open and in good condition.

Two types of internal FRP reinforcement are used in the substructure and superstructure. Piles and girders are prestressed with longitudinal 0.6-in.-diameter CFRP strands. The 24-in.-square piles have transverse CFRP square spiral confining the strands, and the 54-, 72-, and 78-in.-deep Florida I-beam girders have GFRP bars for transverse and shear reinforcement. Cast-in-place concrete caps, columns, and bridge decks are reinforced with cages and mats of GFRP bars, spiral, and stirrups. In general, the strand and bar sizes, shapes, and spacing are similar to those commonly used with traditional steel reinforcement. However, the amount of FRP material used typically is slightly more than the amount of steel reinforcement it replaces. The specific reason for this difference in reinforcement amounts depends on the design action considered. In some cases, because FRP material is less stiff than steel, more FRP reinforcement is required. This is particularly the case when serviceability (such as deflection) controls. In other cases, conservative limits in design guides and codes may limit the allowable tensile force in FRP bars.

CFRP strands are shipped to the precast concrete plant on spools, in a similar fashion to traditional steel strand, although special chucks must be used to grip the CFRP.

Any FRP reinforcement—glass or carbon—that needs bends is preformed

Glass-fiber-reinforced-polymer reinforcement has been placed for a pile cap. After installing the side forms, the concrete will be placed.



Glass-fiber-reinforced-polymer reinforcement was used in a cast-in-place concrete bridge deck and for the stirrups, which can be seen protruding from the prestressed concrete Florida I-beam girders.

to the required shapes before delivery to the precast concrete plant or jobsite. FRP reinforcement cannot be field bent; it must be formed to the desired shape as the polymer matrix initially cures. All FRP reinforcement—both glass and carbon—is approximately five times lighter than the steel it replaces, so shipping and handling are easier and more economical. FRP is generally stronger (with a higher tensile strength), but less stiff, than the equivalent steel it replaces, and designers must account for these variables in the design process.

It is important to recognize that when the North Carolina Department of Transportation (NCDOT) decided to build the $60 million all–FRP reinforced bridge replacement, the agency drew upon knowledge derived from decades of research, as well as design guidance and specifications from the American Association of State Highway and Transportation Officials (AASHTO) and the American Concrete Institute (ACI).[1–3] Committees at AASHTO, ACI, and PCI have focused on internal FRP reinforcement for years.

While large-scale concrete structures reinforced with GFRP bars and prestressed with CFRP strands may be new to many readers, the technology is proven, tested, codified, and reliable. The key benefits of internal FRP reinforcement, which include greater durability, longer design life, and substantially reduced maintenance, have been demonstrated.[4] FRP-reinforced concrete bridges have been successfully in service in Japan since 1988, in Canada since 1997, and in the United States since 2001. NCDOT constructed a GFRP-reinforced bridge deck in 2005 and has actively funded research on concrete prestressed with CFRP strands since 2014.

Despite the extensive documented record regarding internal FRP reinforcement, extra steps are being taken on the Harkers Island Bridge to ensure quality. NCDOT has set up the testing and certification programs at each FRP reinforcement manufacturer. Additionally, quality-control tests are being conducted independently at North Carolina State University (NCSU) on FRP strands and bars randomly sampled from the precast concrete plants and the jobsite. NCSU's test results are compared with manufacturers' results and with design values. Randomly sampled bent FRP bars from the precast concrete plants and the jobsite are being tested in tension after being embedded in concrete to evaluate the quality of the bends. So far, all test results exceed design requirements.

The Harkers Island Bridge replacement project is an outstanding example of how the new, but proven, technology of internal FRP reinforcement can be successfully implemented at a large scale to create durable infrastructure.

NCSU students have the opportunity through the Deparment of Civil, Construction, and Environmental Engineering to learn from projects such as the Harkers Island Bridge replacement and the complementary research projects being performed on FRP materials. For example, undergraduate civil and construction engineering students study the behavior of GFRP reinforcing bars in the Civil Engineering Materials course, and they are introduced to GFRP reinforced concrete in the Reinforced Concrete Design course. At the graduate level, students can learn about FRP repairs in the Strengthening and Repair of Concrete Structures course.

Graduate students have the opportunity to lead original, state-of-the-art research projects associated with actual construction projects. They interact directly with bridge engineers, contractors, manufacturers, and inspectors throughout the project, gaining first-hand perspectives from all stakeholders. These experiences prepare them to be well-rounded engineers upon graduation.

Undergraduate research assistants also contribute to the projects. They participate in research while at the same time observing the design and construction process of an in-progress project.

Before a Florida I-beam girder is cast at the plant, prestressed carbon-fiber-reinforced-polymer strands and glass-fiber-reinforced-polymer transverse reinforcement are placed. Students at North Carolina State University have the opportunity to participate in research projects associated with actual construction projects.

References

1. American Association of State Highway and Transportation Officials. 2019. *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete*. 2nd ed. Washington, DC: AASHTO.

2. AASHTO. 2018. *Guide Specification for the Design of Concrete Bridge Beams Prestressed with Carbon-Fiber-Reinforced Polymer (CFRP) Systems*. Washington, DC: AASHTO.

3. American Concrete Institute (ACI). 2022. *Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary*. ACI CODE-440.11-22. Farmington Hills, MI: ACI.

4. Benzecry, V., J. Brown, A. Al-Khafaji, R. Haluza, R. Koch, M. Nagarajan, C. E. Bakis, J. J. Myers, and A. Nanni. 2019. "Durability of GFRP Bars Extracted from Bridges with 15 to 20 Years of Service Life." ACI Foundation website. https://www.acifoundation.org/Portals/12/Files/PDFs/GFRP-Bars-Full-Report-with-Addendum.pdf.