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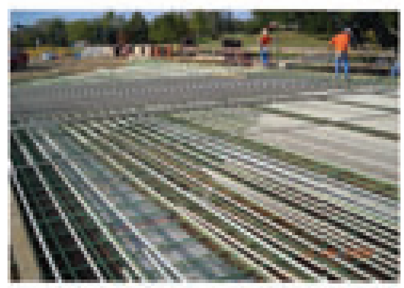
**One of the primary failure mechanisms in reinforced concrete bridge decks is corrosion of the steel reinforcing bar. When steel corrodes it expands, causing the adjacent concrete to spall, resulting in failure of the deck and limiting the useful life of the structure.**

The typical solutions to this problem are to find ways to protect the steel by adding concrete admixtures, increased clear cover, using coated reinforcing or nonferrous steel or high-performance concrete. Ultimately the various protection methods will fail and the steel will corrode, and the bridge will deteriorate.

A chloride-rich environment, such as a bridge deck that is subjected to deicing salt or natural salt water, accelerates the rate at which steel will corrode. Inevitably the concrete will crack, leading to avenues for chlorides to penetrate to the steel. Additionally, a chemical electrolytic cell, or battery effect, is created within the bridge deck and accelerates corrosion of the reinforcing steel. Glass fiber-reinforced polymer (GFRP) rebar is impervious to attack by chlorides and will not corrode and spall the concrete. GFRP eliminates the typical failure mechanisms and extends the service life of the bridge.

## Stacking decks

Using GFRP requires only a small additional investment at the time of construction. The cost increase for the deck is generally only a couple of percent



# Leaning ON GLASS

*Industry pushes for the use of glass fiber-reinforced rebar*

higher than epoxy-coated steel bars. In addition, the cost of GFRP rebar is much more stable than steel rebar, and firm pricing can be held for a duration of several months. Many years of additional service life are anticipated because of the use of GFRP rebar. The return on the initial investment is substantial, even neglecting the hidden costs such as traffic interruption. Taxpayers and society benefit greatly from the increased service life of the bridge.

GFRP bars have been used as concrete reinforcing for the better part of the last decade, and invaluable experiences have been gained from many projects. Many of these projects resulted from Federal Highway Administration (FHWA) and Innovative Bridge Research and Construction (IBRC) funding. To date over 75 bridge decks have been built with GFRP reinforcing in the deck just in the U.S. and Canada. All bridges that have been built thus far are performing as intended and continue to perform successfully.

## Seeking guidance

Based on the experience gained from past projects, several authoritative consensus design guidelines have been published or are in the draft stages. One of the more important documents, in its third iteration, is the American Concrete Institute (ACI) Committee 440 Document, 440.1R-06 "Guide for the Design and Construction of Concrete Reinforced with FRP Bars." In Canada, two important design documents have been published: the CSA S6-06 "Canadian Highway Bridge Design Code," which now includes provisions for the use of GFRP bars, and the CSA S806-02 "Design and Construction of Building Components with Fibre-Reinforced Polymers." Worldwide, several other guidelines are in various stages of publication such as the FIB Task Group 9 in Europe, the GB in China and the JSCE "Recommendation for Design and Construction of Concrete Structures using Continuous Fiber Reinforcing Materials."

Most importantly, for the American bridge design community, "AASHTO LRFD Bridge Design Guide Specifications for GFRP Reinforced Concrete Decks and Deck Systems" were approved by committee T6 in May 2008. These documents offer the bridge designer authoritative design guidance using traditional reinforced concrete design methodology with variations described to account for the different mechanical properties of GFRP bars. The basic principles of GFRP reinforced concrete design are very straightforward and easily adapted by the structural engineer.

To ensure that GFRP bars used in the bridge deck are furnished with properties used by the design engineer, various test standards are available. Testing of GFRP bars is generally performed based on the test methods outlined in ACI 440.3R-04 "Guide Test methods for Fiber-Reinforced Polymers for Reinforcing or Strengthening Concrete Structures." ACI 440.3R was developed to facilitate the 440.1R-06 design guide and to transition to ASTM standards. Many individual test methods have already been published as ASTM standards, such as ASTM D7205/D "Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars." The standardized tests allow for easy determination of relevant engineering properties and give the engineer and bridge owner confidence that the bars will meet the properties that were assumed for design calculations. These documents also enable independent confirmation of properties and quality assurance testing and enable multiple GFRP rebar suppliers to bid on individual projects.

Very recently, ACI has published construction specifications describing in mandatory language provisions governing testing, evaluation and acceptance of GFRP bars and describing the permitted constituent materials, limits thereof and minimum performance requirements for GFRP bars to be used as concrete reinforcing (ACI 440.6-08). A companion specification, 440.5-08, covers construction aspects of the use of GFRP bars such as bar placement, preparation, repair of GFRP bars, field cutting and concrete placement. These documents enable the bridge owner to prequalify potential GFRP bar suppliers for approved bidding and aid site engineers and contractors in successfully monitoring and installing GFRP bars in the field.

## Choosing life

As mentioned earlier, there have been many successful bridge projects where GFRP bars have been used in the decks, railings, abutments and approach slabs. The amount of GFRP in bridges has varied significantly, from top mat only in a single span to no steel reinforcing within the deck, medians and barriers.

The Floodway Bridge over the Red River near Winnipeg is the largest FRP-rebar-reinforced bridge constructed to date. It consists of two bridges with eight spans each and a total length of 1,142 ft.

**Designing with GFRP does not require any special education; it is very similar to conventional reinforced concrete. This is a huge benefit for the engineering community.**

The deck was built using the steel-free deck concept and used GFRP rebar for both the top and bottom mats as well as the barrier walls. The project required over 150 tons of GFRP rebar (GFRP is one-fourth the density of steel and would be equivalent to approximately 1.2 million lb of steel). Only two areas of the deck had steel: a stainless steel shear connector for the barrier walls and a steel strap located underneath the deck.

A full life-cycle analysis was done on the bridge, and GFRP rebar reinforcing was chosen based solely on life-cycle costs. The Floodway bridges were some of the first GFRP-rebar-reinforced bridge decks to be constructed without receiving some form of grant money. It is important to note that there were no outside factors influencing the decision to use GFRP rebar; it was chosen simply based on cost-versus-benefit analyses.

In 2005, the ISIS research network in Canada published some key findings on the durability of GFRP bars in bridge decks. Their series of publications on the "Durability of GFRP Reinforced Concrete from Field Demonstration Structures" involved extracting GFRP bars from bridges throughout Canada that had been in service from five to eight years. Detailed analysis showed that there was no degradation of the internal GFRP bars in the bridge structures, leading a group of leading civil engineers from around the world to declare the "Winnipeg Principles" advocating the use of GFRP bars in bridge decks.

## Staying close to steel

Design of GFRP-reinforced members is very similar to design using conventional steel reinforcing. The mechanics principles are the same, but differences in the material properties require slightly different computations. The biggest change is that GFRP is linear elastic up to failure and does not yield. Typically, in place of the ductile steel reinforcing being mandated to be the weak link in the reinforced concrete, with GFRP bars the designer must choose a failure mode of either rupture of the GFRP bar or compression failure of the concrete. Safety factors differ between the two failure modes to ensure a conservative design. In either case, because of the low modulus of the GFRP bars, tremendous service load deflections and large crack widths will be present prior to failure. In fact, deflections and crack control most often control the design.

Careful effort was made in the various design guidelines to keep the design procedure as similar to steel-reinforced concrete design as possible. The ACI 440.1R-06 guide, for instance, addresses ultimate limit states for shear and flexure as well as all of the serviceability issues. Utilization of GFRP bars is very conservative, because of the relative novelty of GFRP reinforcing. For example, the ACI 440.1R-06 guide limits the sustained stresses on an GFRP bar to just 20% of the guaranteed short-term properties.

"Canadian Highway Bridge Design Code" (CSA S6-06) has a chapter devoted to GFRP-reinforced concrete design. It addresses similar topics as ACI 440.1R-06, but also provides for the use of an empirical design method.

The empirical method assumes that the deck can be modeled as a simple truss. The compression forces of the truss are carried through arching action by the concrete, and either internal reinforcing or an external steel strap carries the tensile force. When an external steel strap is used it is known as the "Steel Free Deck Design." The Red River Floodway project, mentioned earlier, was designed using the Steel Free Deck Design method.

Barrier walls are designed based on a performance specification, and it is critical that several options be available to the designer. There are several different GFRP-reinforced barrier wall configurations that have been tested. The Texas Department of Transportation has crash-tested a TL-3 barrier wall, and the University of Missouri-Rolla performed pendulum tests on a TL-2 barrier wall. CSA S6-06 has four configurations available for design. Three of the four use no steel reinforcing, and the fourth wall only requires steel studs for the connection to the deck.

## In multiples

As mentioned previously, ACI has developed testing guidelines to evaluate the material properties of the bars. ASTM committee D30 is transitioning these test methods into ASTM documents. Test methods are important with these new materials to enable verification of individual bar properties and give confidence to the engineer that the design will be properly built. With standardized tests, the engineer can easily determine if a prospective supplier meets the near-term design properties and if the bar will perform in the long term as anticipated. The standardized testing procedures also eliminate proprietary GFRP systems and thereby allow a designer to accept multiple bids from suppliers.

**Installation and construction of a bridge deck using GFRP rebar is very straightforward with very few differences from epoxy-coated rebar.**

The guidelines are a great tool to prequalify manufacturers so that multiple bids can be received with confidence that all the bar properties meet the specifications required. Again, the ISIS network in Canada has taken the lead in this area by publishing "Specifications for Product Certification of FRP's as Internal Reinforcing in Concrete Structures."

## Sinking the float

Generally, installation and construction of a bridge deck using GFRP rebar is very straightforward with very few differences from epoxy-coated steel rebar. Due to the low modulus of the materials, bars need to be supported with chairs at a spacing of two-thirds that of steel rebar. It is recommended that 50% of bar intersections be tied using plastic-coated tie wire.

GFRP is less dense than concrete and in theory could float in the concrete, so it is generally recommended that the mats be tied down every once in a while. Experience has shown that during concrete placement there is enough foot traffic on the bars to keep them from floating up. Flotation of bars can occur on large vibrating beds in a precast plant, but this phenomenon has yet to be observed on the construction of a bridge deck.

Of chief concern should be the potential for abrasion of GFRP bars onsite. ACI construction specifications describe remediation in such instances.

## More on the way

The extended service life anticipated by the use of GFRP rebar benefits all parties involved, from the owner to the end user. When life-cycle costs are examined it is less expensive to use GFRP reinforcing then traditional steel or epoxy-coated steel. The initial cost premium to use GFRP bars in the deck is on the order of just a couple of percentage points.

Designing bridges with GFRP internal reinforcing is no longer a novel and new concept. There have been many successful projects, and every year more and more bridges are built with GFRP reinforcing. Designing with GFRP does not require any special education; it is very similar to conventional reinforced concrete. This is a huge benefit for the engineering community, because it allows for the same design avenues currently used. The procurement stages are the same, and no changes need to be made constructing the deck using GFRP. With the durability of GFRP, the possibility to build bridge decks with a service life of 75 to 100 years could be achievable.

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