Repair of concrete bridges with FRP

Concrete bridges have been around since the early 20th century and have been growing steadily in numbers since their introduction. Thanks to its low cost and general versatility, concrete is the primary building material used in constructing bridges. However, even with all of their advantages, concrete bridges are subject to damage, design and construction errors and more stringent requirements due to design Code changes.

Mo Ehsani, QuakeWrap, Tucson, Arizona, USA

Concrete bridge repair can be difficult and costly. Lanes on highway bridges must be closed, resulting in traffic congestion and delays. Keeping clearance beneath the bridge is often important, especially when the bridge crosses a trafficked waterway, a railway, or another section of highway.

In the past, the traditional methods of repairing concrete bridges were to either replace the damaged concrete and/or enlarge the concrete section by encasing it in concrete. The latter requires dowelling of reinforcing steel into the old concrete. Beginning in the 1960s, it also became common to bond steel plates to the tension zone of a flexural member, using either bolts or adhesives. Adding more steel reinforcement in the form of a plate to the interior of the structure often poses logistical problems, as the heavy plates are often very long and cannot be easily manoeuvred and lifted in a confined space.

This adds significantly to the repair cost. Additionally, when steel plates are exposed, care must be taken to protect them against corrosion. Adding more reinforced concrete or steel to the outside of the structure is easier, but the extra mass can cause problems with both clearance and the dead load of the structure. Recent advances in fibre composite technology offer an innovative alternative to these traditional methods.

Fibre-reinforced polymers

Fibre-reinforced polymers (FRPs) were developed in the 1960s and they are exceptionally strong and versatile materials. These materials were originally used in the defence industry, but their high cost prevented their application in construction. However, with the end of the Cold War in the 1980s there was a surplus of these materials, which resulted in considerable cost reductions, making them economical solutions for many construction applications. FRPs are constructed from high-strength fibres, such as carbon, Kevlar or glass, that are embedded in a resin matrix. The matrix protects the fibres and distributes the external loads among the fibres. The FRP products used in the construction industry fall into two general categories: wet lay-up and pre-cured shaped.

Wet lay-up process

In the wet lay-up process, fabrics of glass or carbon are saturated in the field with a low-viscosity resin matrix and the wet fabric is applied to the substrate. A thin layer of high-viscosity resin (tack coat) must be applied to the surface of the substrate to ensure the saturated fabric stays in place and does not slide down.

Pre-cured sections

Pre-cured sections are manufactured in plants and can be either in the form of reinforcement or thin plates (typically 1mm thick × 20–50mm wide). These plates are externally bonded to the substrate using a high-viscosity resin.

In the wet lay-up system, FRPs are very flexible prior to curing and can easily be applied to surfaces of varying shapes. The pre-cured sections are stiffer, but all FRPs are light enough to be handled without lifting equipment on the job site and thin enough to be applied in low-access spaces without interrupting operations, adding as little as 3mm thickness to the substrate. This minimal change in the total mass of the structure also eliminates the need to make foundation adjustments or other costly correctional construction associated with the use of a heavier material, such as concrete, thus reducing the overall project costs. After a few days, the FRPs are cured and become two to three times stronger than steel.

Repair applications

These attributes of FRP make it ideal in many bridge repair applications. To improve the flexural strength of the deck and beams, FRP can be applied to the tension face of the structure, in the same way as steel plates, to improve flexural strength. Figure 1 shows a bridge where strips of carbon laminates are being applied to the deck. To facilitate the installation, shallow grooves (about 4mm deep) were machined into the deck surface.

(Photo: QuakeWrap)

Figure 1: Installation of laminated carbon strips for strengthening a bridge deck.

Figure 2: Shear strengthening of ends of beams in a pedestrian bridge with glass-fibre-reinforced polymer (GFRP) fabric.

Figure 3: Corrosion of reinforcing bars in a bridge pier.

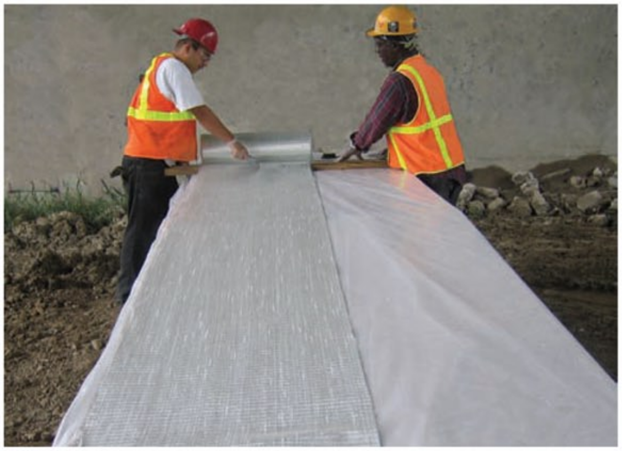

Figure 4: Cutting of GFRP fabrics is simple and can be achieved on site.

Figure 5: Workers on lifts wrapping the bridge pier with GFRP.

After the carbon plates are bonded to the deck, the grooves are filled with epoxy and then a coating of asphalt is applied to the entire bridge. Similarly, FRP can be used to strengthen beams in shear. Figure 2 shows the concrete beams in a pedestrian bridge in a middle school in Arizona, where the ends of the beams are being strengthened by wrapping them in a GFRP fabric. In this case, six beams were retrofitted over a period of two days while the school was closed for the Christmas holiday.

Perhaps the most popular application of FRP to date has been in confinement of bridge piers for improved seismic behaviour. Prior to the mid-1970s, design Codes required a minimal amount of lateral ties for columns and bridge piers. As a result, all older bridges and buildings are susceptible to premature brittle failure in the event of an earthquake. Wrapping of the piers with FRP fabrics provides additional confinement for the longitudinal steel bars, in much the same way as do steel ties or hoops. As a secondary benefit, the lateral confinement offered by the FRP wraps increases the compressive strength of the concrete, and thus, the axial capacity of the piers.

Corrosion

FRP also offers an economical solution to the problem of corrosion of reinforcement in bridges. Corrosion is an electrochemical process that requires oxygen in order to occur. When a pile or pier is wrapped in FRP, it is isolated from the surrounding environment, thus preventing the flow of oxygen. This can stop, or significantly lower, the rate of corrosion. In a recent study conducted at the University of South Florida, researchers offer evidence of the effectiveness of FRP in reducing the rate of corrosion[1]. Piles wrapped in FRP showed a far slower rate of corrosion than the unwrapped control sample. This dramatic decrease in the rate of corrosion implies many far-reaching applications for the use of FRP in preventing and slowing the rate of corrosion.

Case studies

In summer 2006, the Indiana Department of Transportation was dealing with severe corrosion problems in the piers of several highway bridges due to defective storm drains. The downspout that would have carried runoff water to the ground was not installed, and water poured out of the drain at the top of the structure. The salt and de-icing chemicals from the roadway had mixed with this water, and as it splashed down the piers they began to deteriorate; Figure 3 shows one such pier. The capacity of the piers was reduced and they needed to be repaired. The corroded piers were encased in two layers of GFRP fabric. The fabrics can easily be cut to the desired dimensions in the field, as is shown in Figure 4. These fabrics created a protective barrier against further corrosion and erosion, while strengthening the piers and providing more ductility. Perhaps the best part of this operation was that each 9.7m-tall pier was wrapped in only five hours, using only a crew of four workers and two person lifts. Figure 5 shows the crew during installation and the finished pier is shown in Figure 6.

FRP can also be used to compensate for construction errors. For example, in a recently completed highway bridge in the US it was discovered that half of the necessary reinforcing steel in the slabs was accidentally left out. QuakeWrap provided a design involving a single sheet of carbon-fibre fabric bonded to the underside of the bridge. This one layer of FRP will double the moment capacity of the structure, more than making up for the missing reinforcement. More importantly, the repairs can be performed very quickly, allowing the bridge to be put into service in a short time.

Conclusion

Bridges are an important part of every city's infrastructure and an increasing percentage of these bridges are being made out of concrete. Despite concrete's durability, given the unavoidable aging of structures, changes in Codes, and inevitable design flaws, finding ways to repair and retrofit concrete bridges is an important step in the upkeep of a transportation system. FRPs offer an economical, modern alternative to some of the more traditional methods that have developed thus far. ■

■ Reference:

1. AMERICAN CONCRETE INSTITUTE. ACI SP 230: *7th International Symposium on fiber-reinforced polymer (FRP) reinforcement for concrete structures.* Farmington Hills, November 2005.

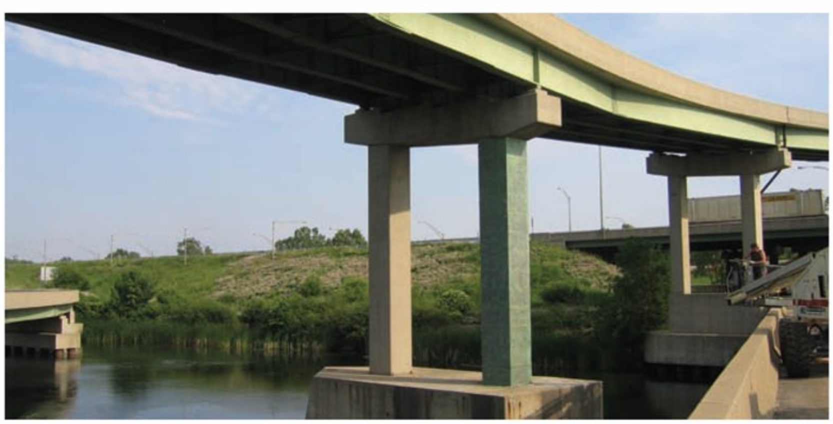

Figure 6: The finished bridge, showing the wrapped column on the right and the unwrapped column on the left.