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Innovations in Infrastructure

Construction projects involving bridges, buildings and underground tunnels benefit from breakthroughs in composite materials.

By Mary Lou Jay

The U.S. infrastructure is crying out for attention. According to the American Society of Civil Engineers, the country needs to spend $4.5 trillion by 2025 to fix the country's roads, bridges, dams and other critical structures. But that's not likely to happen soon, especially since government budgets at every level will be strained for the foreseeable future by the economic fallout from COVID-19.

One way to get the job done is to find alternatives to current methods of infrastructure construction. The global composites industry is exploring several technologies that could provide more cost-effective and longer-lasting solutions to these pressing needs. Here are three examples.

Bridge Repair Minus Traffic Jams

Failing bridges are a problem in many parts of the world. In the U.S. alone, more than 231,000 bridges need repair or replacement, according to the American Road & Transportation Builders Association. But bridges closed for repairs often result in unhappy motorists sitting in snarled-up traffic.

FiberCore Europe, based in the Netherlands, has developed a temporary bridge structure that could help ease traffic congestion in these areas in partnership with KWS (a Dutch infrastructure construction company and subsidiary of international construction company VolkerWessels) and in close cooperation with the Dutch Ministry of Infrastructure and Water Management. Made from lightweight FRP, the temporary spans can be placed on an existing bridge. This solution keeps traffic moving along the accustomed route while providing plenty of space underneath for contractors to repair road surfaces or transitions between the bridge and abutments.

The structure is called HUGO, which stands for HUlpbrug bij Groot Onderhoud in Dutch and translates to English as "temporary bridge for maintenance roadworks." After extensive testing of HUGO, KWS is working with the Dutch Ministry to identify five bridge repair projects that will use temporary structures.

HUGO bridges are built with InfraCore® technology, which is specifically designed for use in heavy-duty, load-bearing structures. FiberCore Europe is the civil engineering and construction arm of InfraCore Company, which is developing, marketing and licensing this technology.

According to InfraCore Company, its technology overcomes the cracking and delamination problems of typical FRP bridges by creating a continuous structural connection of the glass or carbon fibers in a multi-layered laminate. The fabric layers partially overlay one another and are interconnected at a slight angle through the entire thickness of the laminate.

FiberCore has been building pre-fabricated, permanent bridges with InfraCore technology for 10 years and recently produced its one-thousandth structure. The company has also developed SUREbridge (Sustainable Refurbishment of Existing bridges), which extends the life and strengthens the structure of existing concrete bridges with the installation of InfraCore FRP panels over the existing surface.

The 295-foot HUGO prototype consists of a 29-foot middle span made from CFRP so it's only 1.2 feet thick. The approach ramps on each side are built with two 59-foot GFRP sections plus a 15-foot metal ramp. "Keeping this element slender has the advantage of limiting the length of the approach ramps, saving cost and reducing weight," says Martin Veltkamp, FiberCore's design manager. It also provides a 6.5-foot clearance underneath the span for workers making repairs on the permanent bridge.

FiberCore manufactures the HUGO decks at its plant in Rotterdam using a one-shot injection molding system, with vinyl ester resin for CFRP bridge segments and polyester resin for GFRP segments. The entire injection process takes about 90 minutes, and workers can demold and finish the bridge segment the next day.

With this speedy production method, FiberCore can produce an average of five light-traffic bridges a week. "It's really more of an industrial process than a building process," says Simon de

Photo Credit: FiberCore Europe

FiberCore's temporary composite bridge, HUGO, is placed 6.5 feet above the permanent structure and can carry all the bridge's normal traffic while repairs go on underneath.

Jong, InfraCore's founder and CEO.

Because of this factory prefabrication, HUGO decks can arrive at the project site with the grit road surface, railings and even the painted traffic lines installed. "We have pushed the line of what we can do in the factory and what we do on site, gradually taking on more and more so that the time on site is very short," says de Jong.

The HUGO installation is simplified for contractors because the components are packaged as an entire system, including lightweight steel towers to support the bridge segments. A 65-foot bridge section weighs just 9 pounds, so builders only need light equipment to lift and move the elements and steel towers into place.

Once the work on the bridge is complete, the temporary bridge is removed and sent to the next bridge repair site for installation. This makes HUGO both a sustainable and an economical choice for transportation authorities that have long lists of bridge maintenance projects.

"The bridge will be a tool that KWS will reuse on a wide variety of infrastructure projects throughout the Netherlands," says Veltkamp. "We are the first country in the world to be doing this, and I expect this will have huge fallout internationally."

Bridges aren't InfraCore Company's only interest; the company is currently marketing its composites technology to shipyards and aerospace and hopes to expand to other areas as well. Its composite structures should soon be available in the United States. Orenco Composites, headquartered in Oregon, signed an agreement in March to license the application of InfraCore technology.

More Strength, Less Weight

Steel-reinforced concrete is a mainstay of the building industry throughout the world, but it could someday be supplanted by concrete reinforced with carbon fibers. In Germany, the Carbon Concrete Composite Project, known as Project C3, is pursuing the possibilities of this enhanced building material with the construction of the CUBE, a 2,368-square-foot structure made almost entirely with carbon fiber-reinforced concrete.

Funded by Germany's Federal Ministry of Education and Research, Project C3 is a consortium of 160 science and industry partners that have been working together since 2014 to develop materials and technologies for carbon fiber-reinforced concrete. TU Dresden, a public research university and a Project C3 partner, is leading the design and construction of the CUBE.

Built on the Fritz-Förster-Plat square in Dresden, the CUBE

Photo Credit: Iurii Vakaliuk, TU Dresden, IMB

The Carbon Concrete Composite Project, known as Project C3, is currently building the CUBE, a 2,368-square-foot structure made almost entirely with carbon fiber-reinforced concrete.

Photo Credit: QuakeWrap

will be an experimental building where researchers can study the suitability of carbon fiber-reinforced concrete from construction, structural and building physics viewpoints. The building's two carbon fiber-reinforced sections include the box, which is a two-story modular building, and the twist shells, featuring two identical, double-curved structures turned 180 degrees to each other. A steel and glass façade will connect the twists and the box.

The precast concrete box is being manufactured in an automated concrete plant and should be ready by early fall. The twists will be produced on the building site, using the wet spraying method of concrete construction.

"The twists perform the function of both supporting shell and weather shell," says Manfred Curbach, director of the Institute for Concrete Structures at TU Dresden. The shell structures, just 1.5 inches thick, are designed to use as little concrete as possible. They are made with double-layered carbon reinforcements, with thin concrete webs on top of them.

"Extruded polystyrene (XPS) foam blocks are integrated between these webs, which run both lengthwise and crosswise. The pre-formed XPS blocks provide thermal insulation and reduce weight," says Curbach. "A further layer of 4-centimeter carbon-reinforced concrete is placed over this layer and seals the entire surface. This structure forms the whole supporting shell of the twist element."

After that comes a full-surface polyurethane foam insulation, which is also sealed. The final layer is a 1.2 to 1.5-inch shell of white concrete, installed without joints. The supporting shell and the weather shell are connected by glass fiber reinforcement bars.

Current plans are to have the box on site and the two twist shells completed by the end of February 2021. Construction of the steel and glass façade and installation of building services will follow, with an anticipated completion date of June 2021.

The Project C3 team hopes that publicity about the CUBE will help draw attention to the many advantages of carbon fiber-reinforced concrete as a building material. "Carbon-reinforced concrete is sustainable, environmentally friendly, saves material and weighs less," Curbach says. "This offers a wider variety for architectural designs. Carbon is four times lighter and up to six times more durable than steel. It can be recycled, and the material cycle is a closed one." In a closed material cycle, post-consumer or post-production waste can immediately be recycled back into the production cycle.

The hope is that carbon fiber-reinforced concrete will someday replace steel-reinforced concrete in structures like bridges and façades. It can also be used as a supplemental material for strengthening intact steel-reinforced concrete structures, including silos, bridges and buildings.

The initial cost of carbon fiber-reinforced concrete is a concern; 1 kilogram of carbon costs 16 euros, while 1 kilogram of steel costs 1 euro. But this equation does not take into account the many other advantages that carbon has over steel.

"Carbon is four times lighter and six times more durable than steel," says Curbach. "When renovating silos or building ceilings, for example, the lightness of carbon means that reinforcements can be laid much faster. Because of its corrosion resistance, we need much less material and save costs here, too." In addition, Curbach says that the predicted durability of carbon fiber-reinforced concrete is 200 years, while steel-reinforced concrete constructions last 40 to 80 years. Costs can also be reduced with applications suitable for mass production.

The Project C3 team is currently using carbon fibers derived from PAN, but Curbach says that some researchers are exploring ways to produce them from lignin, from carbon dioxide in the air and from algae oil. When lignin carbon fibers do become available, they should be about 50% cheaper than PAN carbon fibers, making carbon fiber-reinforced concrete an even more attractive option.

The light weight of carbon fiber-reinforced concrete will make it easy for contractors to handle. It is easier to transport, and fewer people are needed to perform the work, so builders will be able to reduce installation time by 50% compared to steel-reinforced concrete. Curbach says, however, that production does have to be more precise when the application calls for thin layers and components.

After the introduction of the CUBE next summer, the C3 Project network will drive a broad market introduction of different carbon fiber-reinforced concrete applications. "By 2025, a noticeable market impact and the so-called irreversible process should be initiated, so that market penetration can be achieved by 2030," Curbach says.

Maintaining the Pressure in Minnesota

A new technique for in-place application of a carbon fiber pipe reinforcement has restored the structural integrity of a stormwater tunnel system under Interstate 35W and Interstate 94 in Minneapolis.

The tunnels, which run through the sandstone soil at depths of 50 to 130 feet, often flood during heavy storms. The volume of water is so large that it pushes up through the tunnels' access shafts, exerting enough force to blow off the shaft lids. These cycles of pressurization when the tunnel floods and depressurization when the waters recede have caused leaks in the liner of the tunnel's pre-cast concrete pipe.

Concerned about the impact on the tunnels' structure, the Minnesota Department of Transportation launched a project to repair them. The general contractor was PCi Roads, and the engineering firm was Brierley. For most tunnel sections, workers would poke holes in the tunnel and inject a chemical grout that would seek out water and expand to create a moisture barrier on

When the liner of a storm water tunnel in Minneapolis showed signs of erosion, QuakeWrap built an FRP liner strong enough to handle internal and external pressures on top of the existing pipe surface.

the outside of the pipe. That would stop the leaks.

In one 20-foot-long section of the tunnel, however, the pipe lining had eroded, and engineers feared it would not be able to withstand the internal pressures of the water and the external pressure of soil. QuakeWrap, which specializes in FRP products for infrastructure repair and renewal, and its construction arm, FRP Construction, provided the solution. "The objective was to bring the strength of that short tunnel segment up to the strength of the rest of the tunnel," says Mo Ehsani, president of QuakeWrap.

One of QuakeWrap's products, StifPipe®, is made from lightweight 3D core fabric with layers of carbon or glass fiber reinforcements. When wound on a mandrel, the material can be used to create freestanding pipe liners that can withstand the kind of internal and external pressures found in the Minnesota tunnels. But StifPipe would not work for this application; it simply wasn't possible to get 12-foot-diameter liner pipes through 3 to 5-foot-wide access holes.

Lining the interior of the pipe with CFRP fabric in situ wasn't an option. While three to four layers of CFRP could probably handle the internal pressure, they would not provide enough reinforcement for the external loads of the sandstone soil and the highway traffic above. Ehsani estimates it would take 20 to 25 layers of CFRP fabric to get the desired strength, which would be both time-consuming and expensive.

So the FRP Construction team used a recently-developed adaptation of the StifPipe technology, where the host pipe itself serves as the mold for creating the pipe insert. Because of StifPipe's lightweight core, the team was able to get the desired strength with only eight layers of material.

This approach also provided a new liner that exactly fit the existing tunnel pipe. "Sometimes pipes may not be truly cylindrical, because they have become more oval over the years. With this approach, you don't need to worry about taking measurements ahead of time, because you just apply it to the surface of the pipe," says Ehsani.

After PCi Roads dried out the tunnel areas, FRP Construction brought in the required rolls of composite fabric and buckets of resin through the access shaft, transporting 3,250 feet to the repair area. Then they sealed off the area to get the desired humidity and temperature. After applying a primer, crews installed the StifPipe system, which included both glass fiber and carbon fiber, as well as the 3D core, followed by a chemical-resistant, paint-like top coat. When completed, the structural liner measured 1.47 inches thick.

The entire 20-foot tunnel length was completed in three weeks and should not require additional repairs for a very long time. "Unlike steel or concrete pipes that corrode, these materials are pretty much inert so they will never corrode," Ehsani says. "There's really every reason to believe that these should last 70 to 80 years."

Ehsani believes that the in-place StifPipe application could be a solution that DOT and municipal engineers will welcome. "In terms of cost-effectiveness, this is a much more competitive solution compared to some other available techniques," he says. "Nothing is a cure-all, but this is definitely another tool in the tool box for engineers that are designing these special challenging projects."

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