Composites in Concrete Structures
State of the Practice – Part 2

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GFRP rebar cage being prepared for installation of the soft-eye.

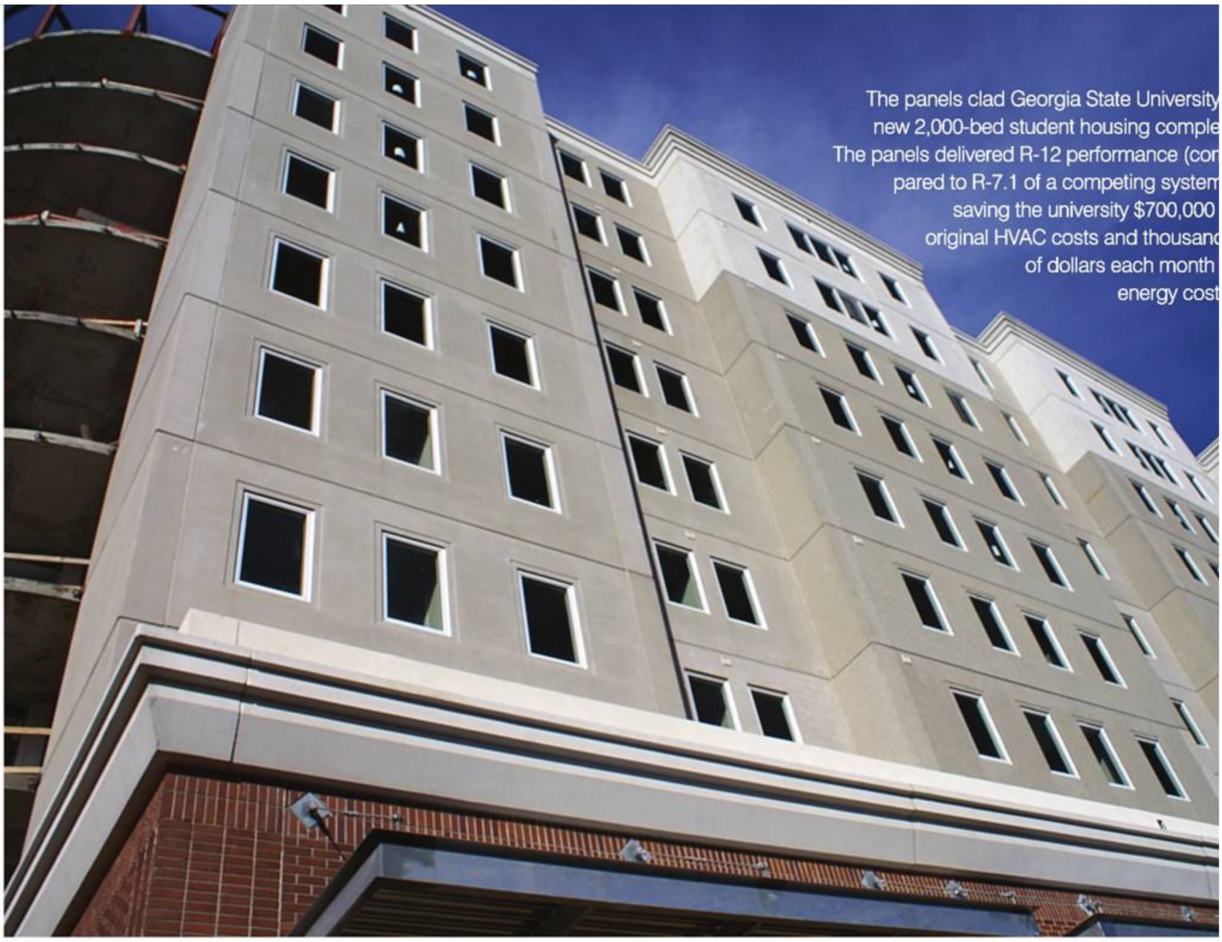
In last month's issue of *CM* magazine, Part 1 of tl article detailed how FRP composites used in con crete reinforcement is a growth market. Enginee and designers are becoming comfortable with sp ifying composites for concrete reinforcement. In Pa 2, we will explore how composites are designed and examine other markets for concrete reinforcement.

Design Approach

There is strong demand from the construction ind try to exploit this technology by developing materi and construction specifications, as well as limit-sta based design specifications, written in mandatory l guage. Composites manufacturers and end-users have gained valuable experience showing the viabil of construction management practices when FRP r inforcement is adopted using traditional bid-lettin processes and competitive bidding from multiple FRP bar suppliers.

Design principles for FRP-reinforced concrete (RC) are fairly well established, and documents co taining design guidelines have been published in North America, Europe and Japan. Design of GFRP-reinforced members is very similar to design using conventional steel reinforcing. The mechanic principles are the same, but the material properties differ and require slightly different computations. The biggest change is that GFRP is linear elastic u to failure and does not yield.

Typically, in place of the ductile steel reinforcing bars mandated as the weak link in reinforced concre designers of FRP bars must choose a failure mode o



The panels clad Georgia State University
new 2,000-bed student housing comple
The panels delivered R-12 performance (con
pared to R-7.1 of a competing system
saving the university $700,000
original HVAC costs and thousand
of dollars each month
energy cost

either rupture of the FRP bar or compression failure of the concrete. Safety factors differ between the two failure modes to ensure a conservative structure. With compression failure of the concrete, a Phi factor of .65 is inherent to the design. With bar rupture, a Phi factor of .55 is used. In either case, due to the low modulus of the FRP bars, tremendous service load deflections and large crack widths will be present prior to failure. In fact, design for deflections and crack control most often control the design.

The design guidelines take care to keep the design procedure as similar to steel-reinforced concrete design as possible. The design guide ACI 440.1R-06 ultimate limit states for shear and flexure, as well as all of the serviceability issues, are addressed. Utilization of FRP bars is very conservative, due to the relative novelty of FRP reinforcing. For example, the ACI guide limits the sustained stresses on a GFRP bar to just 20 percent of the guaranteed short-term properties. A chapter in the Canadian Highway Bridge Design Code (CSA S6-06) is devoted to GFRP-reinforced concrete design. It addresses similar topics as the ACI guide, but also provides for use of an empirical design method. Recently, ACI Committee 440 approved two additional standards, written in mandatory language, that address both material and construction specifications. The availability of these documents will sanction the acceptance of this FRP technology in the concrete industry.

While the use of FRP reinforcement in concrete buildings is within the jurisdiction of ACI, all new bridges financed with fe eral funds must be designed following the American Associatio of State Highway and Transportation Officials (AASHTO) LR Bridge Design Specifications. The lack of AASHTO limit-state based guide specifications that cover the design of FRP RC bri decks and safety appurtenances represents the last barrier to ful utilization of this innovative and competitive technology.

The University of Miami, through its National Science Fou dation Industry/University Cooperative Research Center "Rep of Buildings and Bridges with Composites" (RB^2C), assemble task force that includes individuals from academia, governmen and industry to develop design specifications written in mand tory bridge engineering language. The task force submitted a draft document to the AASHTO Technical Committee T-6 (FRP Composites). While maintaining the AASHTO provisi for the definition of loads, load factors and limit states, the do ment covers specific material properties and detailing of FRP r inforcement. It also defines design algorithms and resistance factors for FRP RC bridge decks and railings. The document cludes a commentary to help designers understand the state-of the-art experimental and theoretical background used to devel the design provisions. Once the document is finalized, Comm tee T-6 will take the guide through the required approval proc

The 31-story Symphony House condominium in Philadelphia used 770 Carbon-Cast Architectural Cladding panels. They weighed 60 percent less than conventional precast, leading to reduced load on the concrete substructure. A smaller building crane was used. HVAC costs are expected to be lower than other exterior wall systems due to superior insulating properties.

for adoption by the AASHTO Subcommittee on Bridges and Structures.

The development of official European GFRP standards lags approximately five to 10 years behind that in North America. Generally accepted and officially recognized guidelines and standards for the testing and the design of GFRP rebar do not yet exist in Europe. Oftentimes, the American and Canadian documents are applied where possible.

The fib Task group 9.3 "FRP (Fibre Reinforced Polymer) reinforcement for concrete structures" is one of the few European bodies working on this issue. It technical report on the "Design and use of fibre rein forced polymer reinforcement (FRP) in reinforced concrete structures" was expected to be published in early 2008.

In conjunction with the application for a general construction authority permit in Germany the German Institute of Construction Technology (DIE has developed a testing procedure for the certificatio of GFRP rebar. This procedure, which contains rath stringent durability and long-term creep tests, is exp riencing international acclaim. The durability testin scheme has been partially adapted in the fib report.

European Applications

Across Europe the conditions and requirements for the installation of construction materials vary greatl Some countries, such as Austria, Germany and the Netherlands, require general construction authority permits. In others, such as Switzerland and Englanc it is sufficient to provide expert opinions and labora tory tests showing that the application is technically sound and safe.

Generally accepted guidelines or standards for te ing GFRP bars and designing GFRP-reinforced co crete members don't yet exist in Europe. As a result the installation of GFRP rebars has been limited mostly to short-term applications in civil engineeri With a few exceptions, the application as permane reinforcement has been restricted to non-structural crack reinforcement.

The 100,000-square-foot Channel Club garage in Monmouth Beach, N.J., replaced a condemned structure that corroded and failed. Parking garages like Channel Club are a desirable alternative to surface lots, which horde land and often create undesirable heating.

Recent substantial increases in the price of stainless steel rebar in Europe have escalated efforts to adopt alternative reinforcement systems, including GFRP rebars. Applications for general construction authority permits for the long-term installation as load-bearing structural reinforcement have been submitted for one project in Germany and the Netherlands. The permits are expected to be granted in 2008. Stronger and more durable bent GFRP bars, as well as special reinforcing elements for the transfer of shear and punching loads, are being developed.

Tunneling Projects

Numerous metropolitan areas across Europe are planning and executing a multitude of urban infrastructure projects. These projects include the construction of tunnels for new subway lines, roadways and sewer lines. As space is often extremely limited in European city centers and traffic congestion is a significant problem, most of these tunnels are built using tunnel boring machines (TBM). The stations are built in open construction pits, and the tunnels are drilled between these pits by the TBM. Disturbing inner city traffic is thereby minimized.

Frequently—and especially if the tunnel is located beneath the ground water table—concrete diaphragm walls or drilled pile walls are built as construction pit walls for the stations. These walls can not be penetrated by the TBM as the steel rebars get caught in the cutter head. As a result, the reinforced concrete in the area of the wall that will be penetrated by the TBM—the so-called

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"soft-eye"—has to be manually removed prior to the passage of the TBM. To allow for this removal, workers undertake special measures to prevent the ground behind the wall from collapsing into the construction pit. These measures are time-consuming, labor intensive and costly.

In western Europe, where labor is very expensive, the installation of GFRP rebar in the soft-eyes of the diaphragm walls is often a financially viable alternative to the conventional construction methodology. As the TBM can easily cut the GFRP bars, it can now penetrate the shaft wall directly. The soft-eye does not need to be cut out manually. While the TBM cuts the shaft wall, it applies enough pressure on the ground behind the wall to prevent any soil failure into the construction pit. Soil stabilization measures behind the wall are no longer required. The overall cost savings can be as much as 200,000 € for each wall penetration.

Recent projects where GFRP rebar has been installed in the soft-eyes of the diaphragm walls include the Vienna Valley Collector in Vienna; the new north-south subway line in Amsterdam; the Randstad Rail project in Rotterdam; the subways in Barcelona, in Budapest and in Berlin; and the new north-south light rail line in Cologne. In Leipzig, GFRP rebar is currently being installed in a temporary recovery tunnel, which is being built to remove steel reinforced concrete piles located in the path of the future city tunnel.

Light Rail Projects

In Europe, GFRP reinforcement has recently been installed numerous times as reinforcement in non-ballasted rail slabs. The advantages are that the material is non-magnetic and electrically non-conducting. GFRP is installed as a direct substitute for the extremely expensive non-magnetic stainless steel rebar.

Today, inner city light rail lines are nearly exclusively built on non-ballasted rail slabs. The rail switches of these lines are operated by electric inductance coils, which are installed on top of the concrete slab. Due to the electric inductance from these coils, steel reinforcing bars in the slab heat up, so they tend to corrode rather quickly. To avoid this problem, GFRP rebar has been installed in numerous light rail projects across Europe.

In addition, steel rebar near signals and vehicle detection devices can cause them to malfunction. Here, the installation of GFRP rebar is also a viable and economic solution. Recent light rail projects where GFRP rebar was installed in the non-ballasted rail slabs include the redevelopment of University Square in Magdeburg, Germany; the Randstad Rail line in The Hague; and the light rail systems in Basel and Bern, Switzerland.

Marine Construction and Sea-front Projects

The city of Blackpool, England, is currently replacing large sections of its seafront wall as part of a complete redevelopment of its ocean promenade. Large pre-cast concrete elements are being installed to replace the old heavily-weathered and worn sea wall. These elements are specially shaped to deflect waves and breakers from the ocean front.

Special formwork was developed to create the architectural concrete surface of the elements. Instead of stainless steel rebar, GFRP rebar is being installed along the exposed face to avoid problems arising out of the corrosion of conventional steel rebars. As the price for stainless steel rebar has risen dramatically the past couple of years, the installation of GFRP rebar is a financially-attractive alternative.

High-rise Applications

The technical and legal requirements for the installation of construction materials are extremely stringent in most of Europe. In countries such as Germany and the Netherlands, single-application permits must be obtained on a project basis to allow for the permanent load-bearing installation of GFRP rebar. As a result, the application of GFRP rebar in permanent high-rise elements has been limited.

In the past couple of years, many cor crete structures across Europe had to be refurbished or replaced because of signi cant structural damage due to the corro sion of the rebars. As a result, a number European design codes were recently ur dated to include more stringent require ments regarding the concrete cover of conventional steel rebar in corrosive en ronments. Greater concrete cover often leads to thicker structural elements.

In rehabilitation projects of parking garages, GFRP rebar may be the only v able solution. First applications of GFR rebar can be an economical alternative stainless steel rebar. In industrial floor slabs, GFRP rebar has been installed in stead of non-magnetic stainless steel rel in areas where driverless transportation systems are operated.

Lately, the interest in GFRP rebar as replacement for stainless steel rebar in electro-magnetically sensitive areas of re search, medical and electronic facilities has grown in Europe. Several projects in Germany and in the Netherlands are in the design phase. Numerous transform slabs and foundation slabs for Nuclear Magnetic Resonance (NMR) apparatus have been built using GFRP rebar.

3-D Grid for Bridge Decks

In 2001, Strongwell Corporation begar working with the Civil Engineering De partment of the University of Wisconsi Madison on a grid system using pultru grating for reinforcement of concrete bridge decks. The first-generation grati grid system was installed on a bridge in Waupun, Wis., in 2003. The following year, the second-generation double-laye grating-grid system was installed on a bridge near Fond du Lac, Wis. In 200 this project was a semi-finalist in the co petition for the Charles Pankow Award for innovation in construction given by the American Society of Civil Enginee

Also in 2005, the third-generation GRIDFORM™ system was installed in Greene County, Mo. This 144' two-la bridge consists of four simple spans. T Greene County project was the runnerfor the 2006 Charles Pankow Award. Interest in this technology is growing. Future plans call for a small bridge deck (540 square feet) in Washington County, Mo. These applications demonstrate that engineers and designers, especially in small counties, believe FRP composites provide economical solutions.

"Greener" Precast Concrete

Precast concrete are used in building facade panels, exterior walls and parking garage components. They are manufactured in off-site factories, then shipped on flatbed trailers to job sites for fast erection. Conventional precast concrete is naturally suitable for green building needs. It's recyclable, it's manufactured from locally-harvested materials, and it minimizes site disruption. It also can reduce energy demands. This means that concrete does a fairly good job of storing heat or cold during the day-night cycle. In warm climates, the concrete becomes cool at night and stays cooler than the air temperature throughout the day, which reduces demand on cooling systems. At night, the concrete releases its heat when the outside air temperature is cooler, thus reducing demand on heating systems. Incorporating carbon fiber grid into the precast as a reinforcing material heightens the benefits.

Since 2004, the AltusGroup™—a national partnership of leading precasters dedicated to innovation—has marketed several products under the CarbonCast® brand. CarbonCast products use C-GRID® carbon fiber grid from Chomarat North America (formally TechFab LLC) that are applied as secondary reinforcement and shear, depending on the product and its use. Unlike the welded wire mesh it replaces, carbon fiber grid will not corrode, is four times stronger than steel by weight and displays relatively low thermal conductivity. These qualities contribute to superior performance that makes already green precast even greener.

Architectural Cladding Panels

CarbonCast Architectural Cladding Panels use carbon fiber grid in the panel face for crack control. Carbon fiber also is used to connect the face to ribs that provide support. Non-weight-bearing cladding panels are used to enclose at building and provide an attractive, functional façade. Conventional precast panels are typically at least six inches thick. Much of the concrete provides a protective cover from moisture and corrosive elements for wire mesh face reinforcing. With carbon fiber grid, precasters can significantly reduce the amount of concrete used. Less concrete means less weight, which reduces substructure materials and lowers fuel costs for shipping. The thinner concrete faces permit the addition of insulation to the wall panels, providing up to R-16 rating and leading to dramatic reductions in energy required to heat or cool a building.

Double Tees

Double tees are the primary component in precast parking structures. The components can be manufactured up to 16' x 53'. Carbon fiber grid is used in the flange, or deck, to replace welded wire mesh. The grid provides superior crack control. Most importantly, it is not subject to corrosion from salt and moisture dragged in by vehicles, especially in colder climates. CarbonCast Pretopped Double Tees can use less protective cover than double tees that use wire mesh, which is susceptible to corrosion. The weight of double tees is reduced by up to 12 percent. Other benefits include reduced substructure materials, lower shipping costs and elimination of chemical treatments to combat corrosion.

High-Performance Insulated Wall Panels

Insulated wall panels are constructed as a sandwich. They use two large sections, or wythes, of thin concrete (usually about two to three inches thick) that literally sandwich a layer of insulation. The panels can be manufactured in widths up to 15 feet and heights of 50 feet or more. High-Performance Insulated Wall Panels use carbon fiber to connect the wythes between the insulation without creating h or cold spots on walls that can plague other connection systems. In addition, carbon fiber's strength allows the two c crete wythes to act as one, providing ou standing load-bearing performance.

In Summary

The extended service life anticipated by use of GFRP rebar benefits everyone fro the owner to the end user. When life cy costs are examined, it is less expensive to use GFRP rebars than traditional or epo coated steel. The initial cost premium t use GFRP rebars in a bridge deck is just couple percentage points. Designing bridges with GFRP rebars is no longer a novel and new concept and does not require any special education, as it is very similar to conventional reinforced concr This is a huge benefit for the engineerin community because it allows for the sam design avenues currently used. The dura ity of GFRP rebars and their many pote tial applications paint a bright picture fo the future of composites.

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