INNOVATIVE USE OF FRP FOR SUSTAINABLE PRECAST STRUCTURES:
Using carbon-fiber-reinforced grids in walls and other components

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Introduction

Fiber-reinforced polymer (FRP) materials have gained acceptance for civil engineering infrastructure as a result of substantial research and development efforts over the past 20 years. The most common use of FRP in infrastructure is for repair and strengthening of existing structures. FRP is an attractive choice for these applications since it is often cost-effective, easy and quick to install, and does not significantly affect the mass or geometry of a structure. Due to its high strength-to-weight ratio and non-corrosive nature, FRP is well-suited for use as internal reinforcing for concrete structures. Its use as reinforcing bars or prestressing strands in new construction has thus far been limited; however, recent advances in the precast concrete industry have enabled more widespread use of FRP in new construction with a variety of new applications emerging. This paper briefly reviews the history of the use of FRP as internal reinforcement in concrete structures and presents recent innovative developments on its use for the precast concrete industry.

Early Applications

Using FRP for internal reinforcement in precast concrete structures has been demonstrated to be effective in a variety of field applications. In 1993, bulb-tee bridge girders pre-tensioned with carbon FRP (CFRP) tendons were used in the construction of the Beddington Trail Bridge in Calgary, Canada, as shown in Fig. 1(a). These tendons were the first application of FRP materials in the precast industry in North America [1]. The CFRP tendons were instrumented with fiber optic sensors to continuously monitor the condition of the bridge. Field testing, shown in Fig. 1(b), of the bridge showed no signs of degradation of the girders after 15 years in service.
In 1997, harped CFRP strands and CFRP stirrups were used to fabricate prestressed Type 6 AASHTO girders for the Taylor Bridge in Headingly, Canada, as shown in Fig. 2. The deck of this bridge was also reinforced with CFRP bars. This bridge received the PCI Harry H. Edwards Industry Advancement Award. Due to the lack of existing design codes at the time, an extensive experimental research program was conducted to evaluate the flexural behavior of prestressed concrete girders fabricated using CFRP reinforcements. Since then, a number of design guidelines have been published, including the American Concrete Institute design guidelines for the use of FRP as reinforcement and prestressing [2, 3].

FRP Grid

FRP materials are manufactured in a variety of forms including sheets, plates, reinforcing bars, and grid. With FRP bars, increasing the diameter of the bar has the tendency to reduce their overall effectiveness due to the shear lag mechanism required to activate all the fibers within the bar cross-section. Consequently, the recent trend has been to reduce the size of bars such as the small diameter strands used in a grid configuration shown in Fig. 3, which utilize the fibers more effectively.

Precast Double-Tees

In the last few years, small diameter CFRP grid has been effectively used as reinforcement for the top flange of precast double-tees, which are commonly used for parking structures. The use of CFRP grid as reinforcement for the flange of double-tees prestressed with steel strands is shown in Fig. 4. The
flange section of the double-tee is often subjected to chloride penetration which can corrode internal steel reinforcement. The non-corrosive CFRP grid can mitigate this problem. The use of CFRP grid also facilitates production of double-tees in long casting beds by allowing for greater efficiency and reduced production time. The process includes: (1) placing and stressing the steel strands in the casting bed, (2) placing self-consolidating concrete (SCC) in the bed, and (3) using a special machine to place the CFRP grid at a specific depth in the flange to provide optimum performance and efficiency, as shown in Fig.5.

To evaluate the performance of CFRP grid-reinforced flanges, full-scale precast double-tees were tested under uniform pressure as shown in Fig.6 [4]. A special chamber was used for testing, as shown in Fig.7. This chamber provided adequate capacity to create a uniform applied pressure greater than the flexural strength of the double-tee. The beams were subjected to the sustained factored load for 24 hours, as required by the load test requirements of chapter 20 of the ACI 318-08 building code [5]. After successfully resisting the sustained load, each double-tee was tested monotonically to failure. The double-tees were also tested under a concentrated load as shown in Fig.8, with the results satisfying the recommendations of the PCI Design Guidelines [6].
Precast Concrete Sandwich Panels

Load-bearing sandwich panels are typically used in building envelopes to support both lateral loads due to wind or seismic events and gravity loads. The wall panels typically consist of two concrete wythes separated by a rigid foam core. FRP grid shear connectors have recently been used to replace steel pin connectors and solid concrete zones to establish the composite action of the two concrete wythes and reduce thermal bridging. It has been shown that solid concrete zones equaling 1 percent of the panel surface area, or steel pin connectors equaling an area of 0.1 percent of the panel surface area can reduce the insulation properties (R-value) of a wall panel by up to 40 percent [7]. On the
other hand, FRP grid shear connectors have a low thermal conductivity and can be used to produce sandwich panels that are both structurally and thermally efficient. The shear connectors are formed by cutting and placing the orthogonal grid in such a way that the fibers are oriented at a 45 degree angle in order to develop the shear truss mechanism as shown in Fig.9 and Fig. 10.

![Figure 9: Load-bearing precast concrete sandwich panels: cross-section.](image)

Construction of the panels consists of: (1) casting the bottom layer of concrete, (2) placing the insulated rigid foam with FRP grid, and (3) casting the top layer of concrete as shown in Fig.11. An embedment of the grid into the concrete wythes from both sides of 3/4 in. was found to be adequate.

Full-scale panels were tested under a gravity loading acting on the corbels, as shown in Fig. 12. In addition, reverse-cyclic wind load was applied to the panels at levels equivalent to 50 years in service. The behavior indicated that the FRP shear truss provided adequate composite action at both service and ultimate load levels [8].

![Figure 10: FRP grid shear connectors: (a) grid configurations, (b) orientation of fibers.](image)
Currently, detailed design guidelines are being developed that use test results from a comprehensive experimental program of double-shear specimens. Each double-shear specimen is subjected to shear forces, as shown in Fig. 13, and represents a segment of a sandwich wall panel. The composite action and shear flow capacity of the wall segments were examined, as affected by the spacing of the grid, the thickness of the foam, and the type of foam [9]. In addition, some segments were tested under a sustained load for up to one year to determine the safe stress level that can be resisted under sustained loading, as shown in Fig. 14.
Architectural Cladding

FRP grid has also been used for architectural cladding. For architectural products, uniformity of color, crack mitigation, and thermal efficiency are primary considerations. Architectural products also must provide sufficient structure to resist wind pressure. The two concrete wythes in the selected architectural cladding panel are separated by an insulating foam core layer and connected by a CFRP shear grid similar to that used for composite wall panels. CFRP grids are also used as the secondary reinforcement for the exterior architectural diaphragm to prevent cracking induced by temperature and shrinkage. The use of non-corrosive CFRP materials prevents staining and cracking of the architectural finish which can occur due to corrosion and expansion of conventional steel reinforcements.

The performance of the architectural panels was evaluated using the test setup shown in Fig. 15, which involved building a chamber around the panel and supporting the panel in a fashion similar to practice. Each panel was subjected to cycles of positive and negative pressure, successfully sustaining the full factored loading in both directions without cracking [10].
Piles

Currently there is an attempt to use FRP grid to replace steel spiral reinforcement for piles as shown in Fig.16. The grid is to provide confinement of the concrete core. Private testing by the Florida Department of Transportation indicated that the behavior was satisfactory. Work in this area is ongoing.

![Figure 16: Prestressing and FRP grid for confinement of piles.](image)

Conclusions

This paper briefly reviewed the history of the use of FRP as internal reinforcement in concrete structures, and discussed several recent developments related to the use of FRP in the precast concrete industry. The favorable mechanical, chemical, and thermal properties of FRP reinforcement enable the production of increasingly sustainable, durable, and structurally efficient precast products. These recent advances have led to growing acceptance of FRP within the precast industry and also within the wider engineering community.
References