Evolution of FRP Products for Concrete Repair

by Mo Ehsani

Nearly four decades ago, I introduced the use of nonmetallic fiber-reinforced polymer (FRP) products for repair and strengthening of deteriorated beams.[1,2] In that original concept, known as the wet layup technique, fabrics made with glass or carbon fibers are saturated with epoxy in the field and applied to the exterior surface of the concrete. By the next day, when the epoxy cures, the FRP reaches a tensile strength two to three times that of steel. That system has been used on thousands of projects worldwide and several countries have developed design guidelines for such repairs. In a typical design, the FRP is used to supplement the reduction in capacity of the structural element that occurs when the steel area is reduced by corrosion.

There are a few major shortcomings with the wet layup system though. The first limitation is that the fabric must be directly bonded to a concave surface. It means that a corroded steel H-pile, for example, could not benefit from repair with FRP; forcing the fabric to follow the sharp corners of the H-pile will damage the fibers in the fabric. The second limitation is that the surface must be smooth. When a concrete beam or slab is damaged by corrosion, for example, the damaged area must first be patched and flattened with concrete and allowed to dry before the FRP fabric can be applied. This adds cost and time to the project. The third shortcoming is that the fabrics cannot be easily applied underwater unless costly cofferdams are constructed.

To overcome the above shortcomings, I developed the second generation of FRP products denominated as SuperLaminates. This product class was introduced on the 20th anniversary of the publication of my first article in *Concrete International*.[3] These laminates are made by saturating a roll of carbon or glass fabric with resin and subjecting it to heat and pressure using special equipment. The result is a thin laminate with a thickness of about 0.04 in. (1 mm). The main advantage of these laminates is that they eliminate the need for virtually all surface preparation, saving significant time and money. They can also be applied underwater to repair submerged piles.

The steps for repair of a typical column are shown in Fig. 1. Note that the damaged surface in Fig. 1(a) does not have to be patched. Plastic spacers shown in Fig. 1(b) are passed through a zip tie and attached to the column. Longitudinal bars can snap into these spacers. The 4 ft (1.2 m) wide laminate is cut in a length equal to twice the perimeter of the shell being wrapped plus 8 in. (200 mm). The second half of this laminate is coated with an epoxy paste and wrapped around the column and spacers to create a 4 ft tall two-ply shell around the column (Fig. 1(c)). Additional 4 ft tall shells are similarly installed, overlapping the previous shell by 4 in. (100 mm) (Fig. 1(d)). The annular space between the shells and the host concrete is filled with concrete or grout (Fig. 1(e)). The finished repaired column is shown in Fig. 1(f).

The two-ply laminate shell provides significant confinement for the column, equivalent to No. 4 ties at a spacing of 2.8 in. (12 mm diameter bars at 70 mm). The elimination of steel ties makes the repair much easier because only longitudinal bars must be inserted into the spacers. Note that the impervious shell will prevent any moisture or oxygen ingress, drastically reducing the corrosion rate in the column for decades.

These laminates are also ideal for repair of submerged piles without the need for any cofferdam. The product has been tested extensively by the U.S. Army Corps of Engineers.[4] Thousands of piles have been repaired with this system globally for various ports and other clients since its introduction in 2012.

The Third Generation of FRP

This article introduces the latest FRP product I have developed. It can replace three products commonly used on repair projects: formwork, reinforcing steel, and waterproofing. The patent-pending panels, named SPiRe®+,



Fig. 1: Repair of a deteriorated column with a fiber-reinforced polymer (FRP) laminate: (a) damaged surface; (b) installing the spacers and reinforcing bars; (c) wrapping the first laminate to create a shell; (d) wrapping additional laminates; (e) filling the annular space; and (f) completed repair

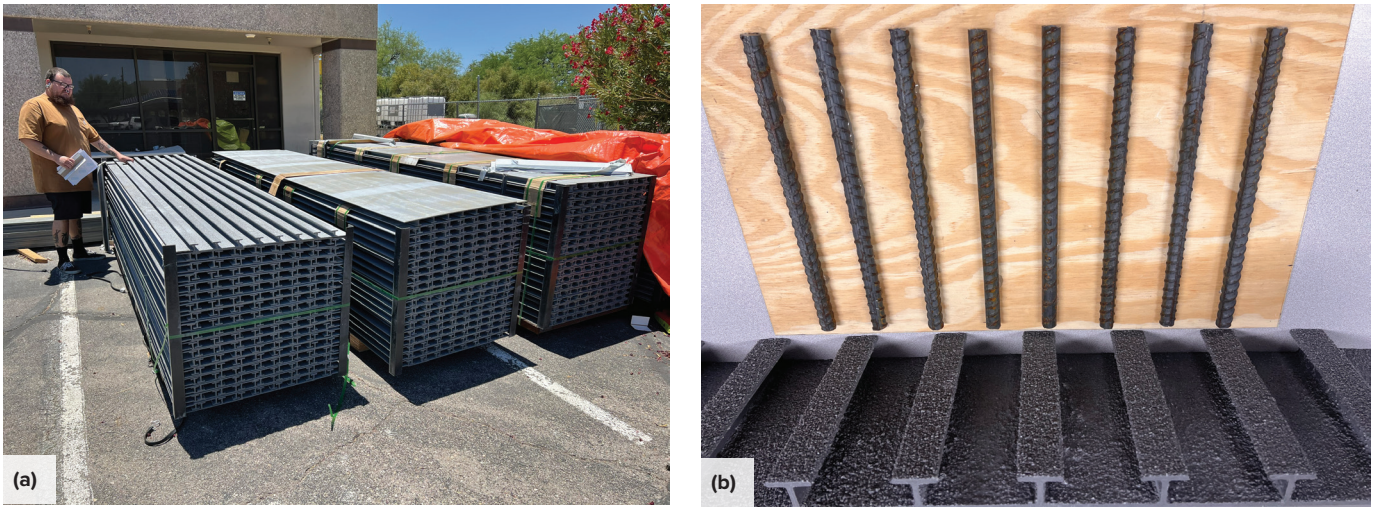


Fig. 2: T-panels: (a) 3 ft (910 mm) wide and 12 or 18 ft (3.7 to 5.5 m) long; (b) close view of grit coated surface and steel reinforcing bars that would provide equivalent tensile capacity

are 3 ft (910 mm) wide and can be cut to any length in the field (Fig. 2(a)). They are constructed with glass fabric using a pultrusion process. The exterior face of a panel is flat and smooth, and the interior face has protruding T-profiles. The interior face is also grit coated for improved bonding to concrete. Together, the flat panel and the T-profiles act as reinforcing elements for strengthening beams, slabs, or walls (Fig. 2(b)). The panel wall thickness is 0.2 in. (5 mm).

For repair of walls or slabs, the edges of the panels are overlapped by 4 in. A sealant is applied on this overlapping region in the field to create an impervious watertight joint. In a typical repair project, the panels are secured to the corroded structure with anchor bolts to create the desired annular space of 2 in. (50 mm) or larger. This annular space is subsequently filled with cementitious or epoxy grout to bond the panels to the host structure. A main advantage of the system is that it requires virtually no surface preparation. The rougher the surface of the host structure, the better the bond between the panels and newly placed grout and the host structure.

Flexural Test

The strength of the T-panels has been demonstrated using the test shown in Fig. 3. An 8 in. wide, 4 in. thick, and 9 ft (2.74 m) long beam was constructed using a Quikrete non-shrink precision grout cast on an 8 in. wide T-panel. Per the grout manufacturer's recommendation, 5-1/4 qt (5 L) of water



Fig. 3: Test specimen: (a) formwork; (b) mixing and placement of grout; and (c) flexural testing of the beam

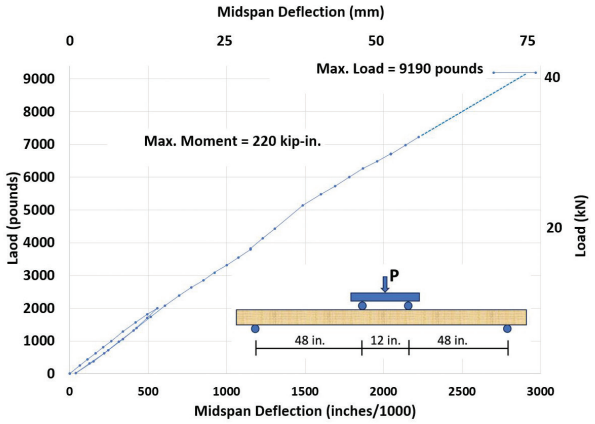


Fig. 4: Load versus midspan deflection of the beam constructed with a T-panel



Fig. 5: Repair of corroded steel sheet piles in Weston, FL, USA, in June 2024

was mixed with each 50 lb (22.6 kg) bag to produce a grout with a consistency between flowable and fluid (Fig. 3(b)). The beam was subjected to a four-point bending (Fig. 3(c)). The load versus midspan deflection results are shown in Fig. 4.

The only reinforcement in the beam specimen was provided by the two T-profiles and the flat plate of the T-panel (Fig. 3(c)). A large number of fine flexural cracks formed along the length of the beam, indicating a good bond between the T-panel and the concrete. The specimen failed at a load of 9190 lb (41 kN), which corresponds to a flexural moment of 220.5 kip-in. (24.9 kNm). In comparison, if this 4 in. thick beam had been constructed with steel reinforcement, it would have required No. 6 Grade 60 steel bars at a spacing of 3.5 in. (20 mm diameter, 500 MPa bars at 120 mm) to provide the same flexural capacity. Figure 2(b) shows this equivalent steel area, demonstrating that the strength provided by these panels exceeds the reinforcement required for most projects.

Repair of Seawalls

Early applications of this repair system have included seawall repair projects, where T-panels offer advantages by eliminating the need for cofferdams. A repair of severely corroded steel seawall in Weston, FL, USA, is shown in Fig. 5. The seawall borders pump stations where excess flood water is pumped from retention ponds into a canal. Repairs were needed because holes in the existing walls (some as large as 1 ft^2 [0.1 m^2]) allowed significant loss of soil. For repair, these walls were sandwiched between two sets of T-panels, one on each side of the wall.

Repair of Beams and Slabs

Corrosion of reinforcing bars in slabs and girders in buildings, bridges, and ports results in loss of load-carrying

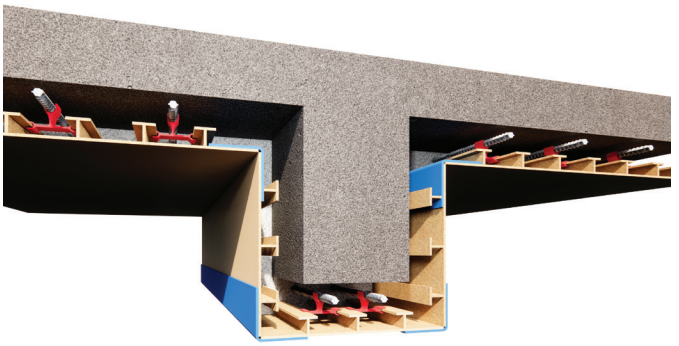




Fig. 6: Concrete beams and slabs can be repaired in a few hours with T-panels

capacity. As shown in Fig. 6, repairs can be executed using forms fabricated from T-panels cut to the appropriate dimensions and connected with pultruded angles fastened along the corners. If necessary, glass fiber-reinforced polymer (GFRP) bars can also be added to these panels using special spacers as shown in Fig. 6. These assemblies can be lifted in place and secured with bolts to the host structure before concrete is pumped into the form through ports. Such repairs can be completed in hours instead of weeks, saving time and cost for the project. The panels serve as formwork and reinforcement, and they also provide permanent protection for the host structure against moisture, salt spray, and corrosion. Note that as part of the design for such applications, a check must be made to ensure proper transfer of loads from the T-panels to the host structure through shear. While rough concrete surfaces do provide a large degree of shear transfer, anchor bolts can be designed to connect the panels to the host structure and provide additional shear transfer capacity if needed.

Construction of Retaining Walls

The panels can also be used for new construction. As shown in Fig. 7, for example, they can serve as formwork and reinforcement for retaining wall. In this example, a conventional footing can be constructed with reinforcing bars extending 2 ft (600 mm) above the top of footing. Two rows of T-panels connected by through-bolts can be placed on the footing, shored, and filled with concrete. The bars extending from the footing will transfer tension to the T-profiles, which are the primary reinforcing element in the wall, through a non-contact splice mechanism. Holes can be drilled in the panels for placement of drainage pipes.

Rising Sea Levels

Rising sea levels and subsidence have resulted in flooding in many coastal and riverfront communities, and some

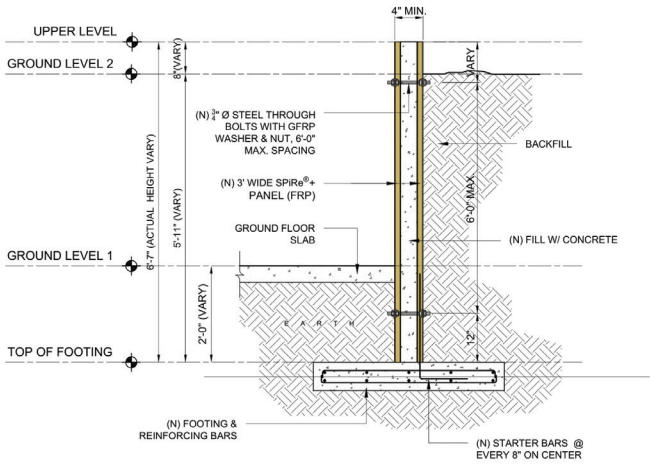


Fig. 7: Construction of retaining walls with T-panels

municipalities have passed regulations requiring that this issue be addressed. As a potential solution, T-panels can be securely connected to the top edge of an existing seawall cap (Fig. 8(a)), additional panels can be placed on the opposite side, and the two layers can be bolted together. By filling the space between these panels with concrete (Fig. 8(b)), a wall extension can be created—often without the need for additional reinforcing bars.

Summary

The evolution of fiber-reinforced polymer (FRP) products for concrete repair over the past four decades has led to the development of a new type of FRP panel. These panels have built-in grit-coated T-profiles that bond to concrete and serve as reinforcing elements for the concrete. In repair applications, the panels can be bolted to existing structures, and the space between the structure and the panels can be filled with

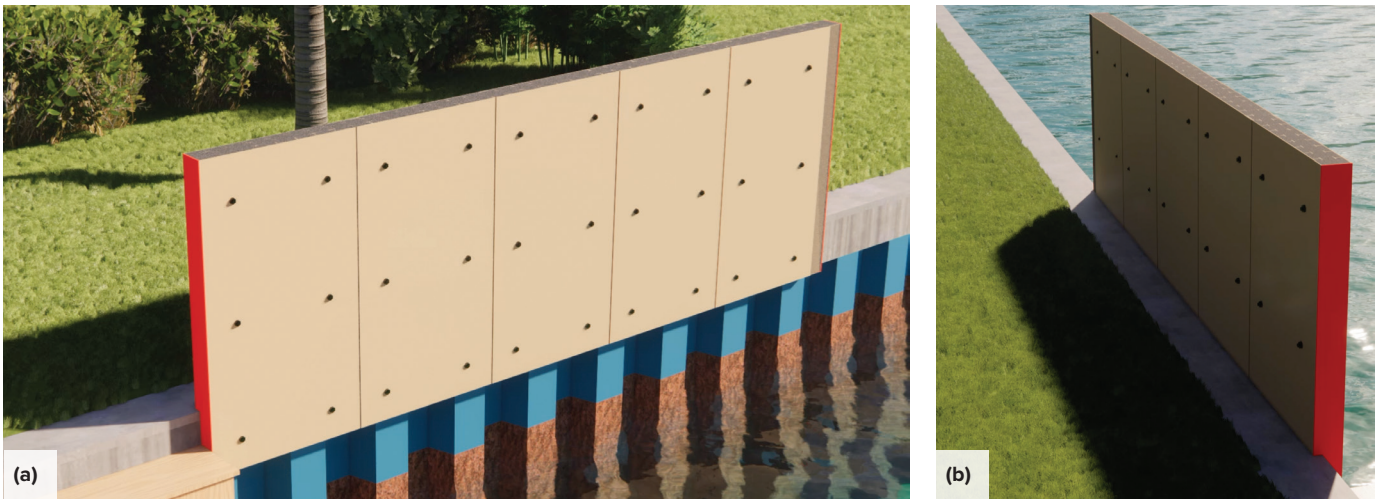


Fig. 8: Seawalls can be extended to limit flooding caused by rising sea levels: (a) SPiRe®+ panels can be attached to each other and at both faces of the seawall at its edge; and (b) the resulting space can be filled with concrete

concrete. As such, the panels serve three functions: formwork, corrosion-resistant reinforcement, and waterproofing. The wide range of applications presented herein attest to the unique features of this product.

For more information, visit **https://pilemedic.com/spire-plus/**.

References

1. Saadatmanesh, H., and Ehsani, M.R., "Strengthening of Concrete Girders with Epoxy Bonded Fiber Composite Overlays," Bridge Research in Progress Proceedings of a Symposium Funded by the National Science Foundation and Sponsored by the Iowa State University, Des Moines, IA, Sept. 26-27, 1988, pp. 117-120.

2. Saadatmanesh, H., and Ehsani, M.R., "Fiber Composite Plates Can Strengthen Concrete Beams," *Concrete International*, V. 12, No. 3, Mar. 1990, pp. 65-71.

3. Ehsani, M., "FRP Super Laminates," *Concrete International*, V. 32, No. 3, Mar. 2010, pp. 49-53.

4. Hammons, M.I.; Strickler, J.S.; Murphy, J.W.; Rabalais, C.P.; Crane, C.K.; and Barela, C., "Pile Wrapping for Expedient Port Repair – PIER Spiral 1," Draft report, Engineer Research and Development Center, U.S. Army Corps of Engineers, Vicksburg, MS, Aug. 2018, 117 pp., https://pilemedic.com/wp-content/uploads/2023/02/Pile-Wrapping-for-Expedient-Port-Repair-PIER-Spiral-1.pdf.

The products described in this article are protected by the following current and pending patents:

- Ehsani, M.R., "Repair and Strengthening of Piles and Pipes with FRP Laminates," US Patent No. 9,376,782 B1, United States Patent and Trademark Office, Alexandria, VA, June 28, 2016, 11 pp.
- Ehsani, M.R., "Structure Reinforcement Partial Shell," US Patent No. 10,968,631 B2, United States Patent and Trademark Office, Alexandria, VA, Apr. 6, 2021, 7 pp.

Selected for reader interest by the editors.



Mo Ehsani, FACI, is Centennial Emeritus Professor of Civil Engineering at the University of Arizona Tucson, Tuscon, AZ, USA. An innovator in the field of repair and retrofit of structures with fiber-reinforced polymer (FRP) products, he holds over 20 patents in this field. Ehsani is a licensed professional engineer in 19 states and a licensed engineering contractor in Arizona and California.