12th International Conference on Short and Medium Span Bridges
SMSB Vancouver 2026

Vancouver, British Columbia, Canada
August 4-7, 2026

Development and Applications of a Multi-Purpose Stay-in-Place FRP Form for Construction and Repair of Structures

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ABSTRACT: Conventional fiber-reinforced polymer (FRP) repair techniques typically require extensive surface preparation before installation, increasing both cost and construction time. This paper introduces a newly developed product by the author that offers significant advantages for new construction, as well as for the repair and strengthening of existing structures both above and below water.
The system consists of pultruded glass FRP (GFRP) panels that are 3 ft (914 mm) wide and can be manufactured in any length. The outer face of each panel is smooth, while the inner face features protruding T-shaped profiles, 1.5 in. (38 mm) tall, which serve as integral reinforcing elements. This inner surface is grit-coated to enhance bond strength with concrete. The panels can be joined by overlapping edges or using L-shaped connectors to form stay-in-place formwork of virtually any configuration. Once bolted to the host structure, the annular space behind the panels is filled with a cementitious grout. The flexural strength of the system—equivalent to that of #6 Grade 60 steel bars at a spacing of 3 ½ inches (20 mm, 500 MPa steel bars spaced at 120 mm) often eliminates the need for conventional reinforcement. Additionally, the impervious nature of the panels removes the need for waterproofing membranes.
The paper describes the development and flexural testing of beams where these panels were the only reinforcing element. Since its introduction two years ago, this technology has been successfully deployed in numerous projects worldwide, including the repair of timber, concrete, and steel seawalls and bulkheads; strengthening of bridge decks, girders, and pier walls; extension of seawalls for sea-level rise protection; and construction of fire- and water-resistant roofs and floors. These applications will also be briefly discussed.

1. INTRODUCTION

Fiber-reinforced polymer (FRP) materials have been used for several decades in the rehabilitation and strengthening of civil infrastructure. Their high strength-to-weight ratio, corrosion resistance, and ease of handling have å them attractive alternatives to conventional repair materials in many applications. In particular, externally bonded FRP systems have been successfully used to strengthen concrete, masonry, timber, and steel structures. Despite these advantages, traditional FRP repair methods often require extensive surface preparation, careful cleaning of the substrate, application of primers and saturants, and a controlled installation process. These steps can be labor-intensive and costly, particularly in marine environments or in projects with difficult access.

In many repair situations, the structural deficiency is accompanied by severe deterioration of the outer surface of the member. In such cases, a repair system must do more than simply add strength; it must also provide confinement, formwork, environmental protection, and often a durable external barrier against water

and aggressive chemicals. Conventional FRP laminate systems are not always well suited to perform all of these functions simultaneously. Likewise, traditional stay-in-place forms often serve only as formwork and do not contribute significantly to structural capacity.

To address these limitations, a new proprietary multi-purpose stay-in-place form system has been developed using pultruded glass FRP (GFRP) panels (watch video). The system is intended for both new construction and the repair or strengthening of existing structures. The panels act as permanent formwork, protective outer shell, and reinforcing element. Once installed and filled with grout or concrete, the system forms a durable composite section that can restore or enhance structural capacity while greatly reducing installation time and simplifying construction.

The concept has broad applicability across many sectors of infrastructure. In marine and waterfront construction, the system can be used to rehabilitate timber, steel, and concrete seawalls, bulkheads, and pier walls (Ehsani 2021). In transportation structures, it can strengthen bridge decks, girders, and substructure elements. In building applications, it can serve as a durable form and reinforcement system for roofs, floors, and wall assemblies where water resistance and corrosion resistance are important. In addition, the panels can be used to extend the height of existing seawalls as a means of improving resilience against sea-level rise and storm surge.

This paper presents the development and structural concept of the system, describes flexural testing carried out to evaluate its performance, and discusses representative field applications that demonstrate its versatility. Particular emphasis is placed on the ability of the panel system to provide flexural reinforcement without conventional internal steel and to function as a practical, durable, and economical alternative to traditional repair approaches.

2. DESCRIPTION OF THE SYSTEM

2.1 General Configuration

The system consists of pultruded GFRP panels manufactured in standard widths of 3 ft (914 mm) and in lengths that can be tailored to project requirements. The product is commercially available as Sheet Pile Repair (SPiRe) system but it will be referred to as GFRP panels in this paper. The outer face of each panel is smooth and dense, providing a durable and impermeable protective surface. The inner face of the panel contains a series of protruding T-shaped ribs, approximately 1.5 in. (38 mm) deep, which act as integral stiffeners and reinforcing elements. The interior face is also grit-coated to improve mechanical bond with the grout or concrete placed behind the panel.


Figure 1: The new panels with T profiles

The pultrusion process allows consistent geometry and high quality control in manufacturing. Because the panels are lightweight, they can be transported and handled more easily than conventional precast or metallic elements. At the same time, they provide sufficient stiffness to function as stay-in-place forms during grout placement and service.

2.2 Connection and Assembly

The edges of adjacent panels can be joined by overlapping flanges or by using L-shaped connectors, allowing the system to form enclosures of many different shapes and sizes. This adaptability makes the system suitable for flat walls, curved sections, corners, box-like shapes, and custom repair geometries.

Depending on the application, the panels can be attached to the host structure using mechanical anchors, bolts, or other fastening methods.

The ability to connect panels in different ways is one of the most important features of the system. It permits field adaptation to irregular existing structures and reduces the need for complex custom formwork. For repairs involving deteriorated seawalls, pier caps, or retaining elements, the panels can be assembled around the damaged portion and then filled with grout to create a new durable outer shell. For new construction, the same panels can be used as permanent formwork that also provides structural reinforcement.

2.3 Composite Action

Once the panels are positioned and attached to the host structure, the annular space between the panel and the existing member is filled with a suitable epoxy or cementitious grout or concrete. The grit-coated surface and protruding T-ribs improve the mechanical interlock between the panel and the infill material, promoting composite action. In this way, the panel is not merely a protective shell but a structural component of the composite section.

The T-shaped ribs play a particularly important role. They serve as stiffeners during handling and installation, but after the grout hardens they also function as reinforcement, analogous in many respects to distributed internal reinforcement. Testing has shown that the flexural contribution of the panel can be substantial and, in many cases, equivalent to or exceeding that of conventional steel reinforcement arrangements commonly used in concrete construction.

2.4 Functional Advantages

The system provides several functions simultaneously:

1. permanent stay-in-place formwork;
2. corrosion-resistant outer shell;
3. reinforcement for flexural and other structural demands;
4. barrier against water ingress and aggressive chemicals; and
5. improved constructability in difficult environments.

Because the outer shell is impervious, the need for separate waterproofing membranes is often eliminated. This is an important advantage in marine and coastal applications, where durability is a primary concern. Similarly, the reduced need for conventional steel reinforcement decreases congestion, simplifies construction, and helps avoid future corrosion-related deterioration.

3. DEVELOPMENT OF THE CONCEPT

The development of this system was motivated by recurring limitations observed in conventional repair and strengthening projects. Many deteriorated structures require not only restoration of lost section or strength, but also protection from continued exposure to moisture, chlorides, and other aggressive agents. In marine environments, for example, corrosion of steel sheet piles, timber piles, and reinforced concrete elements is frequently accompanied by difficult access conditions, tidal effects, and a need to minimize disruption to operations.

Traditional FRP repair systems offer many benefits, but they are generally applied as thin laminates or fabrics bonded to prepared surfaces. Their success therefore depends heavily on the condition of the substrate and the quality of surface preparation. In severely deteriorated structures, achieving a suitable bond surface can be difficult and expensive. Moreover, conventional externally bonded systems do not typically serve as formwork, nor do they provide a substantial protective enclosure for damaged members.

The concept presented in this paper was therefore developed to overcome these limitations. Rather than relying on thin bonded laminates, the system uses a robust pultruded panel that can be mechanically attached to the structure and then filled with grout. This approach reduces the dependency on perfect substrate preparation, allows the repaired section to regain or exceed its original shape, and introduces a durable barrier that protects the repaired member from future environmental attack.

The addition of the integral T-ribs was a major innovation in the product development process. These ribs increase stiffness and provide a means for the panel to contribute directly to flexural capacity. In contrast with conventional non-structural stay-in-place forms, the panel becomes an active part of the structural system. As a result, the same product can serve a wide range of functions across new construction and repair markets.

4. EXPERIMENTAL PROGRAM

A testing program was undertaken to evaluate the structural contribution of the pultruded GFRP panels when used as the primary reinforcement in flexural members. The principal objective of the tests was to determine whether the panels, acting compositely with grout or concrete, could provide sufficient flexural strength and stiffness to replace conventional internal steel reinforcement in selected applications. Additional objectives included observation of cracking behavior, failure modes, and overall serviceability performance.

Three beam specimens were prepared in which the pultruded GFRP panel formed the bottom portion of the section and served as the sole reinforcing element. The remaining section was cast or filled with grout/concrete to produce a composite member. All beams were 10 feet (3.05m) long and 8 in. (200mm) wide. The primary variable was the thickness or height of the beams that were 2, 3, or 4 in. (50, 75, or 100 mm). The dimensions of the beams, span length, panel thickness, rib geometry, and grout properties were selected to represent practical field applications.



Figure 2: Construction and testing of the specimens, showing flexural cracks along the span

The panel was oriented such that the T-ribs projected upward into the grout or concrete, creating mechanical interlock and promoting composite action. No conventional reinforcing bars were used in the tension zone. As shown in Fig. 2, the panels formed the bottom of the specimens.

The grout used was the commercially available Quikrete non-shrink precision grout. Per the manufacturer's recommendation 5 quarts (5L) of water was mixed with each 50 lb (22.6 kg) bag. This resulted in a flowable mix as shown in Fig. 2. Although not tested, the specified compressive strength of the grout was over 6000 psi (41 MPa). The specimens were tested on simple spans (Fig. 2). A concentrated load applied by a hydraulic jack was split in two equal loads that were applied symmetrically about the centerline of the beam. Crack initiation and crack propagation were recorded visually during testing and the applied load and deflection at midspan were recorded; these results are presented in Fig. 3. and Table 1.

Specimens S3 and S4 were tested on 9-ft (2.74m) spans. However, Specimen S2 that had a thickness of 2 in. (50mm) was too flexible for such a long span. The small thickness of this specimen was selected for construction of new flat roof. This specimen was first tested on a span of 4-ft (1.22m) representing the joist spacing for such roofs. The purpose of this test (S2-A) was primarily to determine the stiffness of the system for such applications. The beam proved to be very rigid for such spans, satisfying the deflection limits for such applications. The specimen was next loaded to failure on a 6-ft (1.83 m) span.

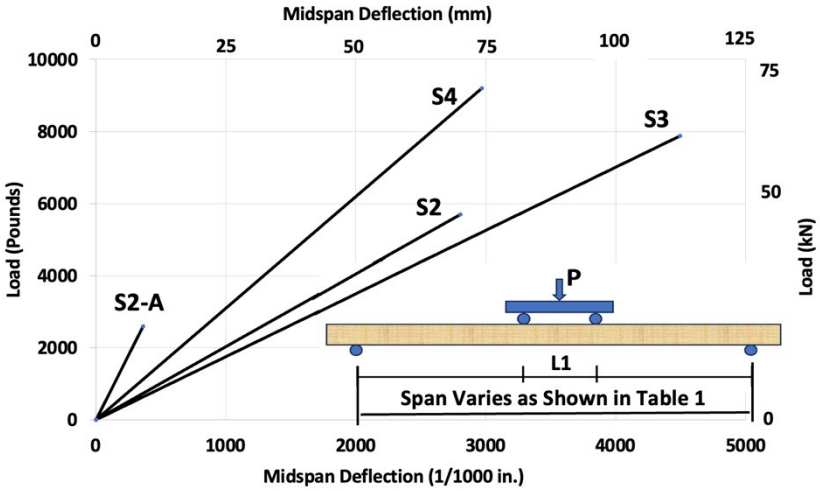


Figure 3: Load vs. midspan deflection for tested specimens

The load-deflection behavior of all specimens was linear to failure. None of the specimens failed by tension failure of the panels. The large number of fine cracks distributed along the length of the beams, proved the good bond between the panel and the grout due to the grit coated surface of the panels. The load causing flexural failure of the specimens is listed in Table 1 and it is also shown as moment per unit width of the panel.

Table 1: Dimensions and flexural strength of the specimens

Beam	B	L1	L2	Flexural Strength		Measured EI	Potential Use
	in. (m)	in. (m)	in. (mm)	k-in. (kNm)	k-in./ft (kNm/m)	k.ft^2 (kNm^2)	
S2	2 (50)	72 (1.83)	4 (100)	147.9 (16.7)	221.8 (83.5)	218 (90)	Flat Roof/Slab
S2-A	2 (50)	48 (1.22)	4 (100)	---------	--------	225 (93)	
S3	3 (75)	108 (2.74)	4 (100)	204 (23)	306 (115)	627 (259)	Seawall Repair
S4	4 (100)	108 (2.74)	12 (300)	220.5 (24.9)	330.7 (124.5)	1126 (465)	Varies

Using the measure load-deflection values shown in Fig. 3, the stiffness (EI) of each specimen was calculated and those values are reported in Table 1. These measurements can be helpful to design engineers planning to use these panels in various applications such as repair of seawall, slabs, etc.

One of the notable findings from the test program was that the flexural contribution of the panel system was approximately equivalent to that provided by #6 Grade 60 steel bars at a spacing of 3.5 in. This comparison is especially useful for designers, as it provides a familiar benchmark for understanding the structural significance of the panel. The equivalency should be interpreted in the context of the tested section geometry, span, loading condition, and material properties. It does not imply universal interchangeability in all structural applications, but it clearly demonstrates that the panel is far more than a non-structural form. In appropriate applications, it can serve as a genuine reinforcing element capable of replacing conventional steel reinforcement.

4.1 Implications for Design

The test results support the conclusion that the pultruded GFRP panel can contribute significantly to flexural behavior and may eliminate the need for conventional tension reinforcement in selected cases. This has important implications for constructability, durability, and cost. By incorporating reinforcement directly into

the stay-in-place form, the system reduces labor associated with rebar fabrication, placement, and cover requirements. At the same time, it avoids the long-term corrosion risks associated with embedded steel.

5. Field Applications

Since its introduction approximately two years ago, the system has been used in a growing number of projects worldwide. These applications demonstrate the versatility of the product across a broad range of structural and environmental conditions. Although the geometry, loading, and installation details vary from one project to another, the same basic concept remains unchanged: the panel serves as permanent formwork, protective shell, and reinforcement.

5.1 Marine and Waterfront Structures

One of the most important application areas for the system is the repair of seawalls, bulkheads, and retaining structures. In these structures, prolonged exposure to salt water, wet-dry cycles, chlorides, and impact often leads to severe deterioration of timber, steel, or reinforced concrete elements. Traditional repair approaches may involve cofferdams, extensive demolition, welded steel repairs, or conventional formwork and concrete placement, all of which can be costly and disruptive.

The stay-in-place GFRP panel system offers several advantages in such cases. The lightweight panels can be installed rapidly with minimal equipment. Once atached, they form a new exterior face that resists corrosion and water ingress. After grout placement, the repaired structure gains both section restoration and enhanced durability. These benefits are particularly attractive where access is limited or underwater installation is required. Figure 4 shows a recently completed steel seawall repair in New York.



Figure 4: Corroded steel sheet pile being repaired with the new GFRP panels (New York)

Figure 5 illustrates one of several corroded waterfront walls in Florida that have been repaired with the new panels. In this application, the pilaster was repaired as well. The red circle identifies the 4 in. × 4 in. (100 × 100 mm) angle sections that are used to connect panel edges, enabling the formwork to accommodate virtually any geometric configuration.

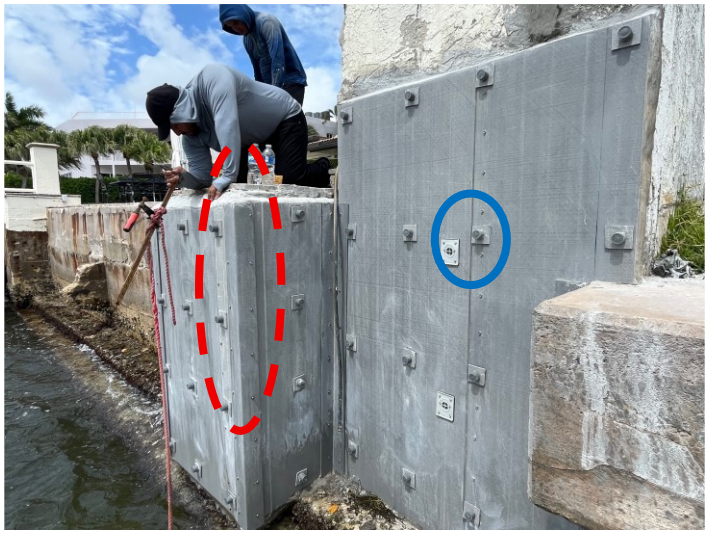


Figure 5: Concrete seawall and pilaster repaired (Florida)

The system employs fiberglass washers fabricated from the same noncorroding GFRP material. The anchor bolts or threaded rods used to attach the panels to the host structure extend through these washers and are secured by nuts on the exterior side of the panels. Plastic caps filled with epoxy are then placed over the nuts to provide corrosion protection. This detail is shown in the blue circle in Fig. 5.

5.2 Bridge Components

Bridge girders are frequently damaged by corrosion or by impact from over-height trucks. Traditional repair methods generally involve removal of unsound concrete, replacement of corroded reinforcement, and restoration of the surface with patching materials. Such procedures are labor-intensive and often require extended road closures and traffic-control measures. With the proposed system, however, surface preparation requirements are minimal. The panels can be assembled using angle sections to create a stay-in-place form tailored to the geometry of the girder and installed during nighttime hours, when traffic disruption is minimized. The annular space is subsequently filled with grout. In addition to accelerating construction, the impermeable panels serve as a protective barrier that helps shield the host structure from future corrosion.



Figure 6: Damaged bridge girders can be quickly repaired with the panels with minimal traffic control

Another application of the proposed system is in the repair of bridge pier walls. The Dickinson Bridge, illustrated in Fig. 7, is located in western North Dakota. The concrete in the pier wall had deteriorated as a result of erosion and minor corrosion. Repair of such walls, particularly when partially submerged, can be challenging. In this project, the repair was accomplished by attaching panels measuring 3 ft (0.91 m) in width and 9 ft (2.74 m) in height to the wall. The panel edges were overlapped by 4 in. (100 mm), and a rubber sealant was applied at the joints to ensure an impervious seal.

As shown in Fig. 7, the panels were bolted to the pier wall to create a 2.5 in. (63 mm) annular space between the panels and the existing structure. This space was subsequently filled with a flowable, non-shrink grout. The entire repair was completed by the contractor in just two days. You can watch a video of this project here.



Figure 7: The pier wall in Dickinson Bridge repaired with the panels (North Dakota)

5.3 Slabs

Another completed project involved the rehabilitation of a corroded prestressed concrete slab in a coastal community in North Carolina. Long-term exposure to ocean breezes and salt-laden air had led to corrosion of the prestressing tendons (Fig. 8). The repair was carried out by attaching the panels to the underside of the slab. The contractor elected to drill holes through the slab from above to inject grout into the annular space. As shown in Fig. 8, the completed repair provided a smooth finished surface. Readers can watch a video of this project here.

5.4 Seawall Extension for Sea-Level Rise Protection

In coastal communities, many existing seawalls no longer provide sufficient freeboard to protect against rising water levels and storm surge. The panel system can be used to extend the height of an existing seawall by attaching the panels to the original structure and filling the space with grout or concrete. This creates a monolithic extension that is durable, watertight, and structurally integrated with the original wall.

This application is particularly important because it allows infrastructure owners to adapt existing assets rather than replace them entirely. The corrosion-resistant nature of the panel makes it especially appropriate for long-term coastal resilience measures. As shown in Fig. 9, the panels can be attached along the edge of the existing pile cap. The overlapping edges of the panels will be sealed with a rubber sealant. Additional panels can be placed facing these on the opposite (land) side. The annular space between the panels is filled with grout or concrete to build a wall that is reinforced with the T profiles. This wall contains no metallic parts, offering decades of maintenance-free service life. If desired, planters, or walkways van be constructed on the land side to provide a more aesthetically pleasing environment for the community.



Figure 8: Corrosion-damaged prestressed concrete slab repaired with the panels (North Carolina)



Figure 9: Extending the height of seawalls for protection of communities from rising sea levels

6. Advantages and Limitations

7.1 Advantages

The proposed system offers several important advantages over conventional repair and construction methods:

- It combines formwork, protection, and reinforcement in a single product.
- It reduces or eliminates extensive surface preparation required for conventional bonded FRP systems.
- It can eliminate the need for conventional steel reinforcement in certain applications.
- It provides an impermeable, corrosion-resistant outer shell.
- It can remove the need for separate waterproofing membranes.

- It is lightweight and easy to handle in the field.
- It is adaptable to many shapes and structural applications.
- It is suitable for both new construction and rehabilitation work, including underwater or marine projects.

7.2 Limitations and Design Considerations

As with any emerging technology, certain limitations and design considerations must be recognized. The structural behavior depends on adequate connection to the host structure and satisfactory bond with the grout or concrete infill. Long-term performance under sustained load, cyclic loading, temperature changes, impact, and environmental exposure should be considered in design. Installation quality, especially grout placement and anchorage detailing, is also important.

In addition, while the equivalent reinforcing value of the panels is a useful design reference, the structural capacity of the system should be evaluated for the specific geometry, loading, and service conditions of each project. Further research and code development will help establish broader design procedures for this class of composite systems.

8. Conclusions

A new multi-purpose stay-in-place FRP form system has been presented for use in both new construction and repair of structures. Based on the development work, test results, and field applications discussed in this paper, the following conclusions can be drawn:

1. The pultruded GFRP panel functions not only as permanent formwork, but also as a corrosion-resistant protective shell and a structural reinforcing element.
2. The T-shaped ribs and grit-coated interior surface promote composite action with grout or concrete, allowing the panel to contribute significantly to flexural strength.
3. Flexural testing demonstrated that beams reinforced solely with the panel system can develop substantial capacity, with performance approximately equivalent to that of conventional steel reinforcement arrangements used in practice.
4. The system can reduce or eliminate the need for internal reinforcing steel and separate waterproofing membranes, thereby simplifying construction and improving long-term durability.
5. The technology is highly versatile and has already been applied to seawalls, bulkheads, bridge elements, pier walls, roofs, floors, and seawall extensions for sea-level-rise protection.
6. The lightweight and durable nature of the panels makes them particularly attractive for marine and waterfront infrastructure, where corrosion resistance and constructability are critical.
7. The system represents a promising alternative to conventional repair and construction methods and offers significant potential for broader use in civil infrastructure.

REFERENCES

Ehsani, M. 2021. Structure Reinforcement Partial Shell. US Patent No. 10,968,631, United States Patent and Trademark Office.