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# Structural Repair of Submerged Piles and Seawalls

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**Abstract**

The dry-wet cycle in marine environments causes rapid corrosion of structures such as piles and seawalls. Because these elements are submerged in water, FRP wet layup techniques cannot be easily implemented. Moreover, diving crews are very costly and any repair system that reduces the diving time could result in significant cost savings.

This paper introduces two new FRP products developed by the author. One is a very thin FRP laminate about 1200 mm wide that can be quickly wrapped around a pile above water to create a shell. The shell is pushed into water, sealed and the annular space between the shell and the pile is filled with grout and optional reinforcing bar. The other is a sandwich construction FRP panel that is used as a stay-in-pace form to repair seawalls and bulkheads. The panels are connected in the field and secured to the existing seawall, creating an annular space between the wall and the panels that is filled with reinforced concrete.

The paper focuses on two projects in the U.S. and Australia where these products have been successfully implemented.

**Keywords:** Pile, Column, Seawall, Bulkhead, Marine Structures, Waterfront, Sandwich Construction

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## Introduction

Waterfront structures are subject to severe corrosion caused by the dry-wet cycle of the tides. The damage is mostly concentrated in the splash zone region, which covers several feet below and above the mean water elevation. Most of these repairs are carried out by diving crews at costs significantly higher than similar construction on land. Thus, in addition to providing a durable repair, it is preferred that the solution be easy to install. This paper describes two such applications that have been developed by the writer in the last decade. One is for repair of submerged piles and the other is for repair of seawalls and bulkheads.

## Repair of Submerged Piles

The traditional FRP jackets that are frequently used to repair submerged piles are shown in Fig. 1. While these jacket materials are durable, they have several major shortcomings. The jackets are comprised of two half shells that are connected in the field around the pile either by a row of bolts or by an epoxied seam. These seams become a line of weakness in the jacket, preventing the jacket from providing any confining pressure around the pile. They also allow moisture or oxygen to penetrate through which will continue the corrosion process. From a construction point of view, the jackets must be ordered to the desired shape and size in advance. This could delay the project and oversized jackets lead to larger annular spaces that must be filled with additional grout.

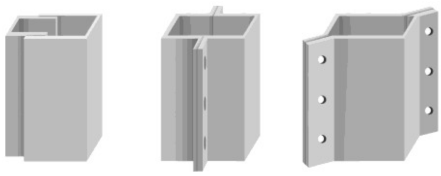

Fig. 1. Typical fiberglass jackets.

Nearly a decade ago the author introduced a new type of FRP laminates called PileMedic® [1]. It is noted that the available equipment and technique used to manufacture narrow carbon strips does not lend themselves to making wider laminates with reinforcing fibers oriented in both longitudinal and transverse directions. Thus, the overcoming of the above shortcomings, namely the manufacturing of *very thin and wide laminate sheets with fibers oriented in longitudinal and transverse directions* is not a trivial matter. Consequently, the development of PileMedic® is perhaps the most significant advancement in FRP products for repair and retrofit in the last two decades. In addition to repair of piles and columns, the laminates are used to repair pressure pipes conveying water or natural gas.

Fig. 2. The new carbon and glass PileMedic®

PileMedic® is constructed with specially-designed equipment. Sheets of carbon or glass fabric up to 1.5 m wide are saturated with resin and passed through a press that applies uniform heat and pressure to produce the laminate (Fig. 2). The patented system [2] offers several major advantages compared to conventional wet layup FRP systems: (a) Using a combination of unidirectional and/or biaxial fabrics, the laminates provide strength in both longitudinal and transverse directions ranging from 62 ksi (430 MPa) to 156 ksi (1080 MPa); similarly the stiffness of the laminates can be customized in both directions; (b) With a thickness as small as 0.01 in. (0.3 mm), the laminates are flexible enough to bend around a 1 in. (25 mm) radius; (c) Manufacturing of the laminates in the plant allows for a higher quality product and testing of the laminates prior to installation; and (d) Repair of structural elements can be completed much faster and with a higher quality.

Since its introduction, this repair system has been extensively tested by various agencies such as California Department of Transportation [3] and Texas DOT. The US Army Corps of Engineers conducted a major evaluation of pile repair systems that led to its selection of PileMedic® as the only pile repair system it uses globally.

PileMedic® laminates are typically offered in rolls that are 4 ft (1200 mm) wide and several hundred feet long. The installation of the system is shown in Fig. 3 where 40 piles were repaired on Barron River Bridge in Cairns, Australia [4]. The expansion of the concrete due to Alkali Silica Reaction (ASR) had caused severe damage to the piles. The local transportation agency had tried a few other solutions that were unsuccessful since the jackets could not resist the pressure induced from the expansion of concrete. PileMedic® laminates can be designed to resist any internal pressure and offer significant confinement for the pile.

When the repair requires the addition of longitudinal reinforcement, special plastic spacers shown in Fig. 3a are supplied that can be strapped around the pile with a zip tie. We have developed similar plastic attachments shown in this video to create a seal at the bottom of the annular space (https://tinyurl.com/y5yf9ayw) Divers can snap longitudinal bars into these spacers. The customized spacers ensure proper positioning of the longitudinal bars. PileMedic® laminate acts as the lateral reinforcement and eliminating ties simplifies the construction significantly. Typical detail for PileMedic® requires wrapping the pile in a shell twice (i.e. 720 degrees) plus an 8 in. (200 mm) extension beyond the starting point. The required length of laminate can be cut from the long roll and the half-length that does not come in contact with the pile is coated with an epoxy paste (Fig. 3b). This epoxy is moisture insensitive and cures underwater, eliminating the need for coffer dams.
The epoxy-coated laminate is passed to the crew for installation (Fig. 3c). In this project, the river was infested with crocodiles and the steel cage shown was necessary for protection of the diving crew. The laminate is wrapped around the pile allowing the second part that is coated with epoxy to bond to the first half, creating a two-ply shell (Fig. 3d). A main advantage of PileMedic® is that the laminate can conform to the geometry of the pile, so the system is

(a) (b) (c) (d) (e)

Fig. 3. Repair of ASR-damaged piles in Australia: (a) spacers and reinforcing bars, (b) applying epoxy to PileMedic® laminate, (c) passing the laminate to the workers, (d) create a shell around the pile and (e) fill the annular space with grout.

virtually a one-size fits-all product. The bottom of the annular space between the jacket and the pile is sealed and the annular space is filed with cementitious or epoxy grout (Fig. 3e). A video describing this project can be watched at this link: http://tinyurl.com/y3csp59v

The unique construction of PileMedic® jackets that have no vertical seams along their height, combined with the tensile strength of the laminate results in a confining pressure on the pile. This effect can be calculated using standard methods and it results in higher axial capacity for the pile. The use of expansive and non-shrink grouts can activate this confinement effect even at service loads. Transfer of loads from the grout to the host pile must also be considered. In some cases, when welding of shear studs is not allowed, the proprietary steel ShearWrap™ is used near the top and bottom of the pile (Fig. 4). These bands are torqued to a predetermined level and transfer the load through bearing and friction.


Fig. 4. ShearWrap™ for transfer of loads

## Repair of Seawalls and Bulkheads

Seawalls, sheet piles and bulkheads constitute a major part of the waterfront infrastructure that extends far beyond ports and harbours. After many years of service, the dry wet cycle in the splash zone of these protective, shallow water structures results in deterioration and loss of structural capacity for sea walls and industrial bulkheads. Few cost-effective repair options are available, and discussions with the commercial ports industry indicates that there is great interest for a solution to this ever-growing marine infrastructure and potentially environmental problem. The compromise of this critical component of infrastructure gets little mention in national dialog but is of equal or greater importance to global commerce and transportation.

The patent-pending Sheet Pile Repair system, called SPiRe® consists of engineered FRP panels using the sandwich construction technique (Fig. 5). A ¼-inch (6-mm) thick core material is sandwiched between various layers of uniaxial or biaxial glass or carbon fabric saturated with resin to create a rigid panel. The panels are 4-feet (1200 mm) wide by 20-feet (6000 mm) long and can be cut to the desired length on the location of installation. The first reported installation of this product was recently completed in Virginia, USA in fall 2018 and is used to demonstrate the various steps in the process.

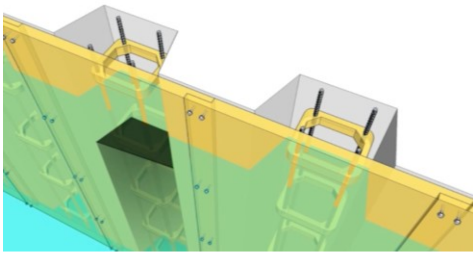

Fig. 5. Schematic of the Sheet Pile Repair (SPiRe®) system.

The site was a pulp and paper plant along a river. Industrial plants located near a commercial waterway will typically use a retention pond or designated area to keep chemicals separated from nearby rivers or channels. Over the years, various chemicals had contaminated the soil on the property. These bulkheads have been traditionally constructed using steel sheet piles at lengths from a few hundred feet to the thousands. Water lines running along these walls – including the splash zones – can also vary from a few feet to dozens of feet. The plant owners were concerned that the corroded bulkhead could be compromised, allowing the chemicals to leach into the river. A video of this project can be watched here: http://tinyurl.com/y4y2285r

The panels are custom-built at the manufacturer's facility in Tucson, Ariz., and shipped to the jobsite (Fig. 6a). In the field, the panels are cut to length (Fig. 6b), and edges of the panels are epoxied together to create an FRP wall of desired height and length. The panels are secured to the corroded wall (Fig. 6c-e) using steel J-bolts. The bottom of the panels extends a minimum of 6 inches (150 mm) below the mudline. Reinforcing cages made with glass FRP bars were placed within the annular space between the SPiRe® panels and the steel bulkhead before the annular space was filled with concrete.

The SPiRe® system is lightweight, highly corrosion resistant, and is installed onsite with minimal service interruption to plant operations. It serves as a durable, chemical resistant, stay-in-place form that prevents leakage of chemicals from the containment area or retention pond into the river. The SPiRe® wall itself is made of non-corroding FRP materials. Furthermore, these impervious layers prevent moisture and oxygen from coming in contact with the existing sheet piles and the newly cast concrete. Since oxygen is the fuel to the corrosion process, this design significantly reduces the future corrosion rate of the structure, providing a long-lasting repair and many years of maintenance-free service.

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(a) (b) (c)
(d) (e) (f)

Fig. 6. Repair of seawall in Virginia using SPiRe®: (a) FRP panels are shipped to the jobsite, and (b) cut to desired length; (c) anchors are installed in the corroded wall, (d) FRP panels are secured to the wall, (e) potentially using divers, and (f) the annular space between the wall and the FRP panels is filled with grout.