Structures & Their Wraps: The Past & Future of Repair with FRP

Mo Ehsani, Ph.D., P.E., S.E.
President, QuakeWrap, Inc., and
Professor Emeritus of Civil Engineering, Univ. of Arizona

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QuakeWrap
Stronger Than Steel

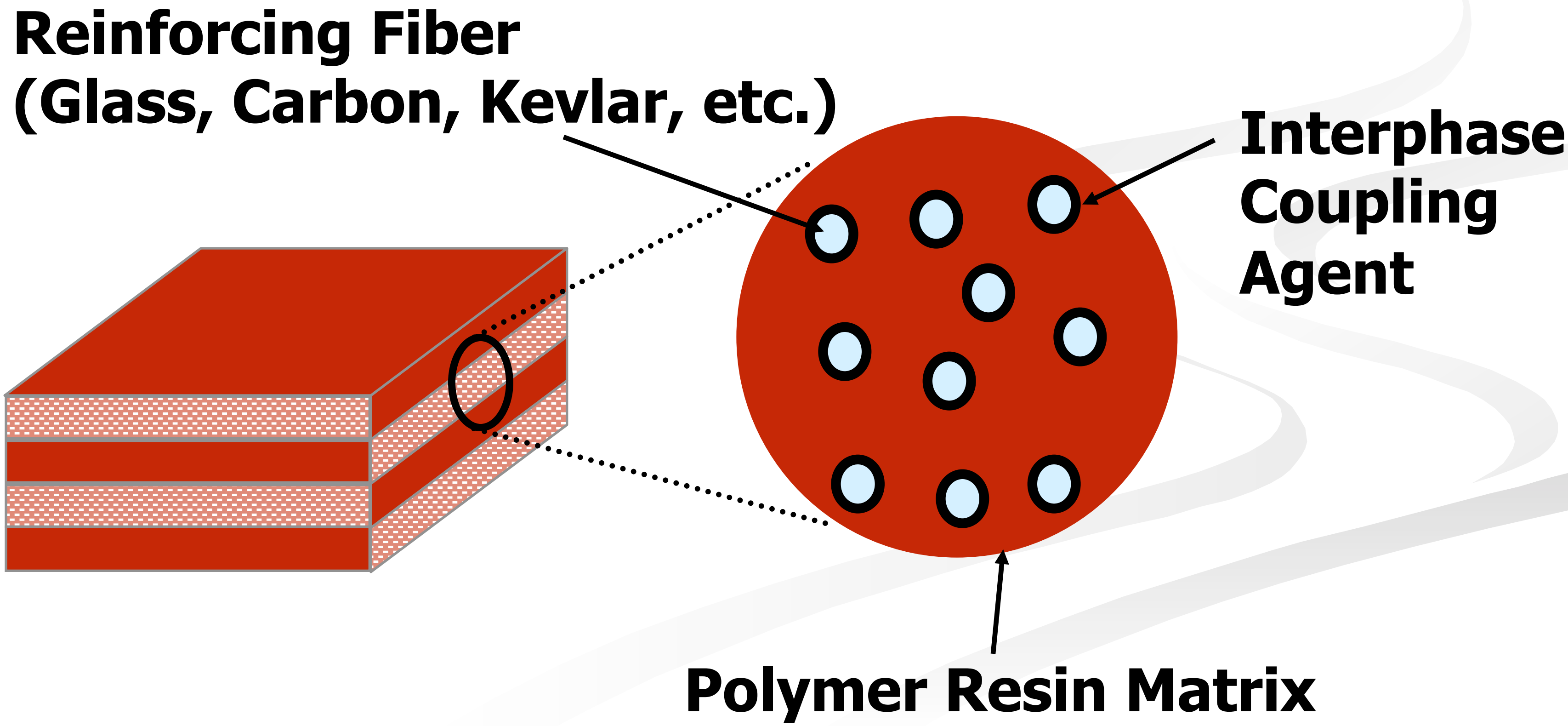
FRP Products

Fiber Reinforced Polymer (FRP)

Why is it called FRP?

It is a Polymer (i.e. epoxy, vinyl ester, etc.) that has been reinforced with a Fiber (e.g. carbon, glass, etc.)

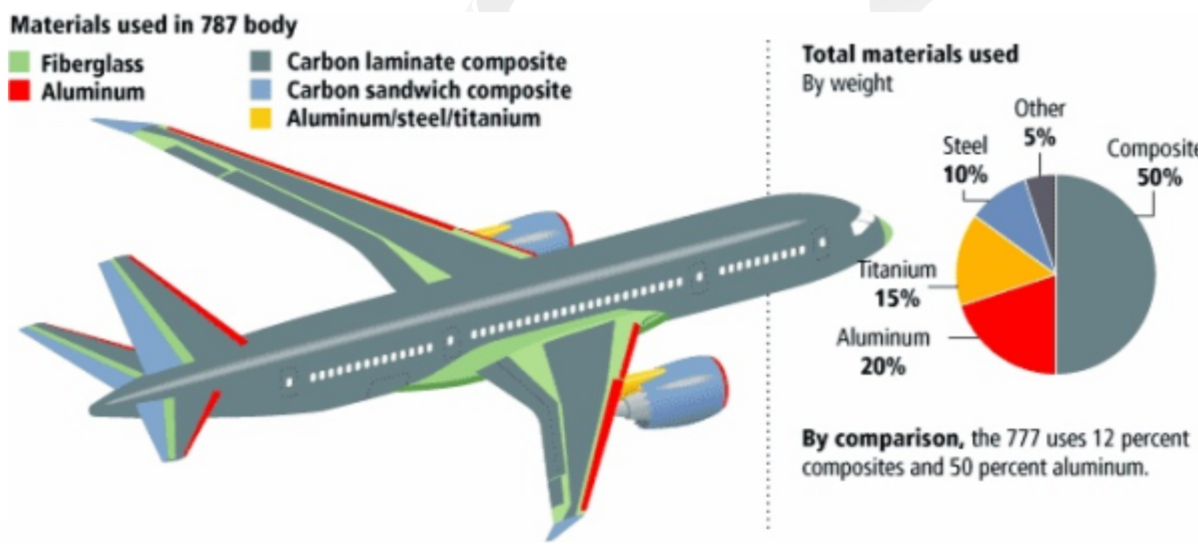
FRP does not have the same strength in all directions; these types of materials are called *anisotropic*



History & Background of FRP

Corvette C1 - 1953

100% FRP Hull



FRP Version 1.0 Introduced March 1990

Epoxy-bonded glass fiber-reinforced plastic plates may provide a corrosion-free solution to increasing the load-carrying capacities of concrete bridges.

Fiber Composite Plates Can Strengthen Beams

by H. Saadatmanesh and M. R. Ehsani

About one-half of the approximately 600,000 highway bridges in the United States are in need of replacement or rehabilitation. Many of these bridges were originally designed for smaller vehicles, lighter loads, and lower traffic volumes than are common today.[1] Consequently, a large number of bridges in this country have inadequate load carrying capacities for today's traffic. Compounding this problem is the loss of strength due to corrosion of reinforcement and spalling of concrete.

These bridges must be either replaced or rehabilitated if present and future traffic needs are to be adequately served. In many cases, maintenance alone will not bring a structurally deficient bridge up to current standards — strengthening (which costs far less than replacement) must also be considered.

Among the methods used to strengthen girders in existing bridges are external post-tensioning and the addition of epoxy-bonded steel plates to the tension flange. External post-tensioning by means of high-strength strands or bars has been successfully used to increase the strength of girders in existing bridges and buildings.[2-7] This method does, however, present some practical difficulties in providing anchorage for the post-tensioning strands, maintaining the lateral stability of the girders during post-tensioning, and protecting the strands against corrosion.

Selected for reader interest by the editors

The addition of epoxy-bonded steel plates to the tension face of concrete girders has been used effectively in Europe, South Africa, and Japan.[1] This method is primarily used to repair and strengthen reinforced concrete elements with insufficient load carrying capacity due to mechanical damages, functional changes, or corrosion. The principles of this strengthening technique are fairly simple: steel plates are epoxy-bonded to the tension flange of the beam, increasing both the strength and stiffness of the girder; the shear capacity of the girders can also be increased by attaching steel yokes to the web.

The advantages of this structural system include ease of application and elimination of the special anchorages needed in the post-tensioning method. A shortcoming of the method is the danger of corrosion at the epoxy-steel interface, which adversely affects the bond strength. An effective way of eliminating the corrosion problem is to replace steel plates with corrosion-resistant synthetic materials such as fiber composites. In addition to corrosion resistance, many fiber composites have tensile and fatigue strengths that exceed those of steel.

Previous studies

Much of the work in the United States has been related to the bonding of steel to steel,[8,9] while in other countries research has primarily been related to the bonding of steel to concrete.[1] Several researchers have investigated the strengthening of existing concrete girders with epoxy-bonded steel plates.[10-15]

MacDonald and Calder studied the behavior of concrete beams externally reinforced with steel plates bonded to their tension flanges.[10] They tested a series of 11.5-ft (3.5-m) and 16-ft (4.9-m) long beams in four-point bending. Each beam had a rectangular cross secton of 6 x 10 in. (150 x 250 mm). It was concluded that substantial improvements in performance could be achieved in terms of ultimate load,

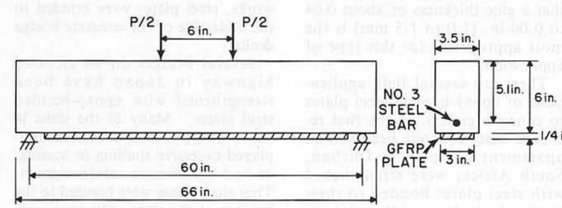


Fig. 1. — Beam test setup.

Original Concept Demonstration

Blast Protection

Fort Bragg, N.C.




Advantages of FRP

- High Tensile Strength *(3-5 times stronger than Steel)*
- Low Weight *(no foundation adjustments required)*
- Anisotropic *(strength depends on fiber orientation)*
- Corrosion Resistance & Acid Protection
- Waterproof
- Excellent Fatigue Behavior
- Speed of Construction
- Versatility
- Odorless & Non-Toxic (Certain Manufacturers)
- Low Cost

Surface Prep (Bond/Pull Test)

A test dolly is attached to the cured surface by an adhesive. When the adhesive is cured the adhesion tester claw is engaged onto the dolly and a force is applied by tightening a wheel/ nut on the top of the tester.

Saturation of Fabric

Plaza at Clayton, MO

Plaza at Clayton, MO

Sample FRP Wet Layup Projects

Tank, AZ

Condo, FL

Chimney, AL

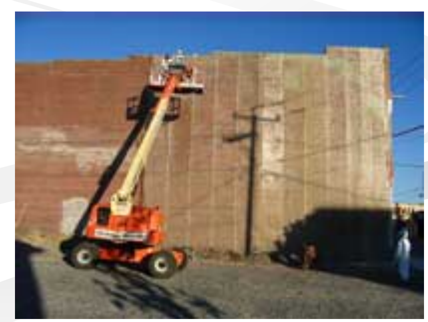
Bridge, NM

Museum, CA

Hospital, AK

Bridge, IN

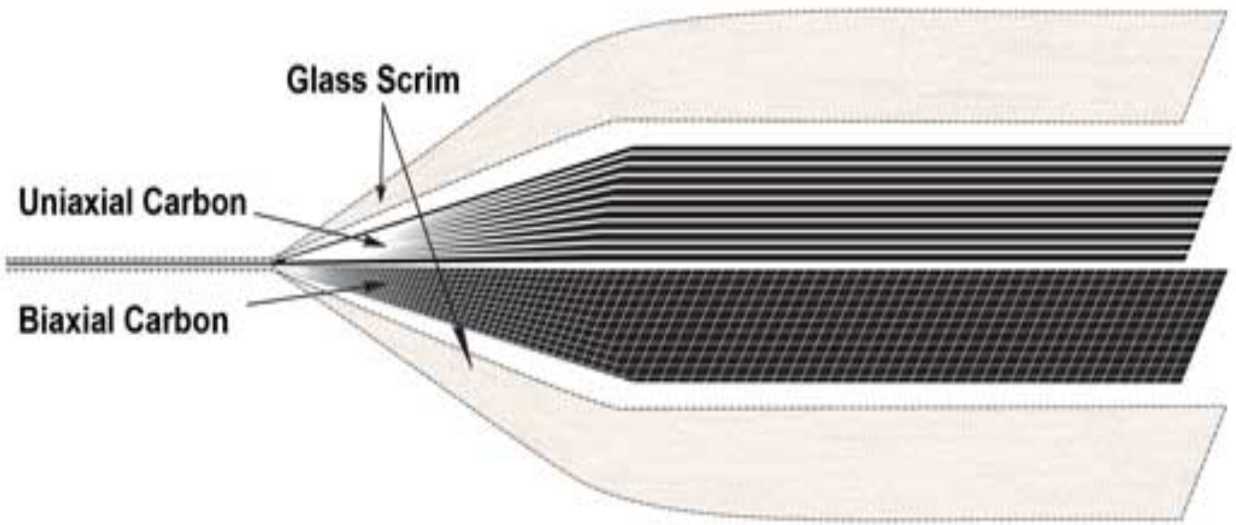
Pipe, Costa Rica



Bldg, PA

SuperLaminates™

Sandwich Construction of PipeMedic™ Laminates (Patent Pending)



- Multi-Axial Reinforcement
- Thickness ≈ 0.01 -0.025 inch
- Tensile Strength ≈ up to 155,000 psi
- Infinite combinations of strength & stiffness can be produced
- ISO 9000 Certified

Rewriting the story 20 years later

FRP Version 1.0

FRP Version 2.0

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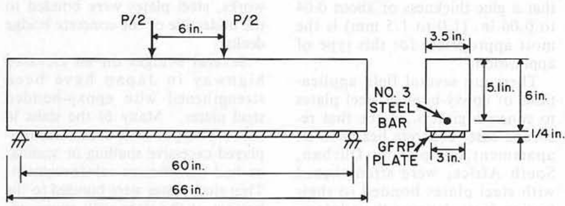


Fig. 1. — Beam test setup.

Selected for reader interest by the editors

FRP Super Laminates

Transforming the future of repair and retrofit with FRP

BY MO EHSANI

Twenty years ago, I presented the findings of a study on strengthening concrete beams with external bonding of fiber-reinforced polymer (FRP) laminates in the pages of *Concrete International*.[1] In the aftermath of the 1989 Loma Prieta earthquake, I proposed an extension of my earlier research to retrofit deficient bridge piers by lateral confinement with FRP.[2] What appeared to be unusual approaches at the time have since become mainstream techniques for the repair and retrofit of structures worldwide.

The high tensile strength, light weight, durability, and versatility of FRPs have made them the material of choice for many repair and rehabilitation projects. To date, numerous bridges, buildings, pipelines, and other structures have been retrofitted with these products worldwide. With the publication of design guidelines,[3] it is fair to say that FRP is no longer an experimental product but rather a well-accepted construction material.

FRP products come in two categories: fabrics and pre-cured laminates. Fabrics offer the widest versatility in the field and are installed with what is commonly referred to as the wet layup method. This technique requires properly trained technicians to prepare resin in the field, saturate the fabric, and apply it to the structural member. Care must be taken to ensure that the fibers are aligned in proper directions and that all air bubbles are removed before the fabric is cured.

Pre-cured laminates are manufactured in a plant, eliminating many of the field errors possible with the wet layup method. They are available in the shape of reinforcing rods or tendons as well as narrow unidirectional laminate strips typically produced in the range of 3 to 4 in. (75 to 100 mm) wide and 0.05 in. (1.3 mm) thick. In the field, these laminate strips are bonded to the exterior surface of the structural element using epoxy putty. In a variation of this approach, known as near-surface mounted reinforcement, laminate strips or rods are adhesively anchored within narrow grooves that have been cut in the structural member.

While the laminate strips offer ease of installation and higher strength than the wet layup system, their use has been relatively limited. The unidirectional reinforcement in laminates makes them primarily suitable only for flexural reinforcement of beams and slabs, with some applications for shear strengthening of beams. Other applications (for example, for pipe or column repairs) are practically impossible. The stiffness of a typical laminate prevents coiling it into a circle smaller than about 30 in. (750 mm) in diameter, and the maximum width of available products (about 10 in. [254 mm]) renders them impractical for use as pipe linings.

SUPER LAMINATES

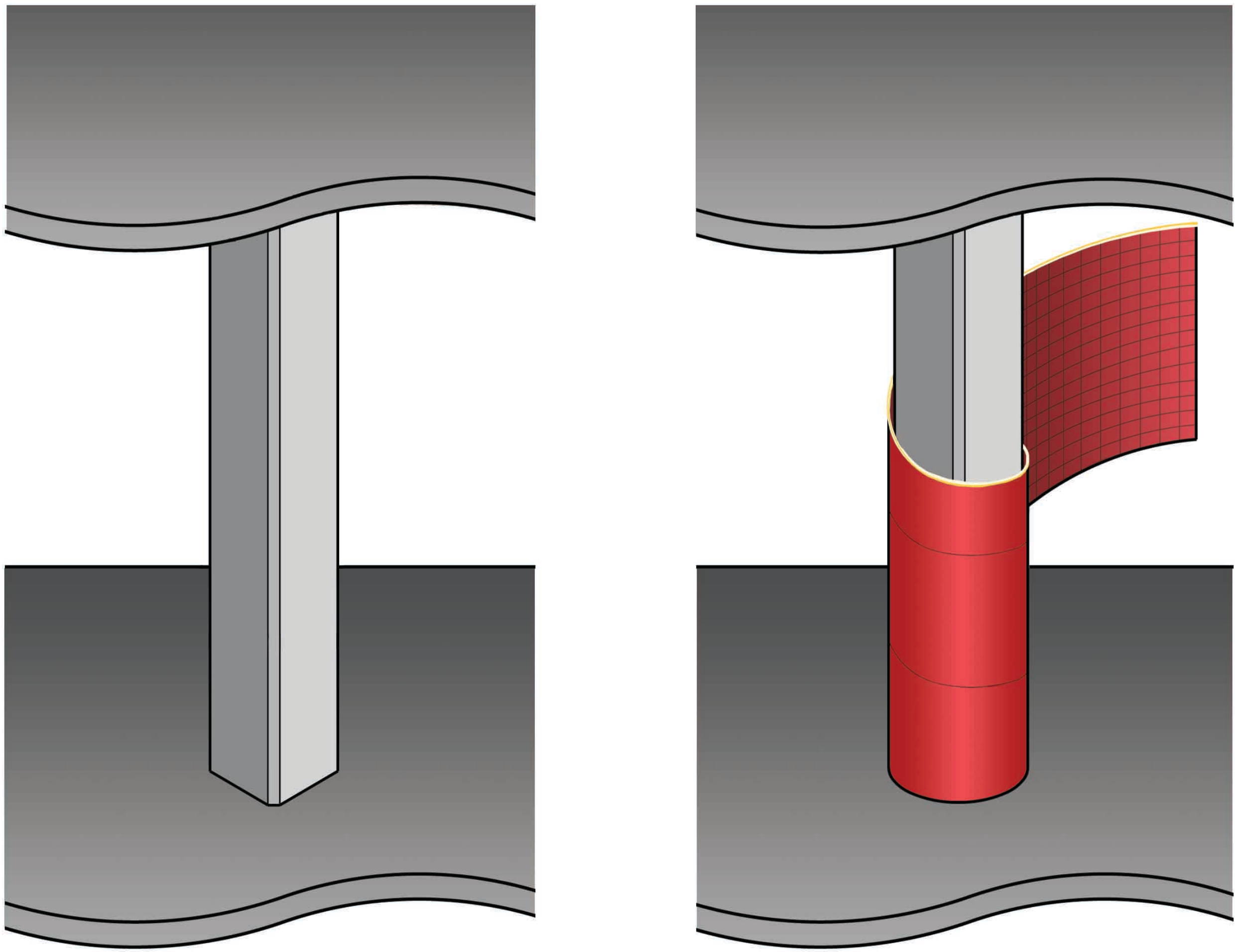
Super laminates represent a huge advance in FRP manufacturing technology. Sheets of carbon or glass fabric up to 60 in. (1524 mm) wide (Fig. 1) are saturated with resin and passed through a press that applies uniform heat and pressure to produce the laminates. Super laminates offer three major advantages:

Fig. 1: Super laminates can be constructed with multiple layers of unidirectional or biaxial fabrics

Advantages of SuperLaminates

- Laminates manufactured in plant
- Significantly reduces construction time
- Improves quality; stronger than wet layup
- Material properties known in advance
- Less dependent on experience of field crew
- Local contractors can be easily trained/certified
- Offers solutions which are impossible with wet layup

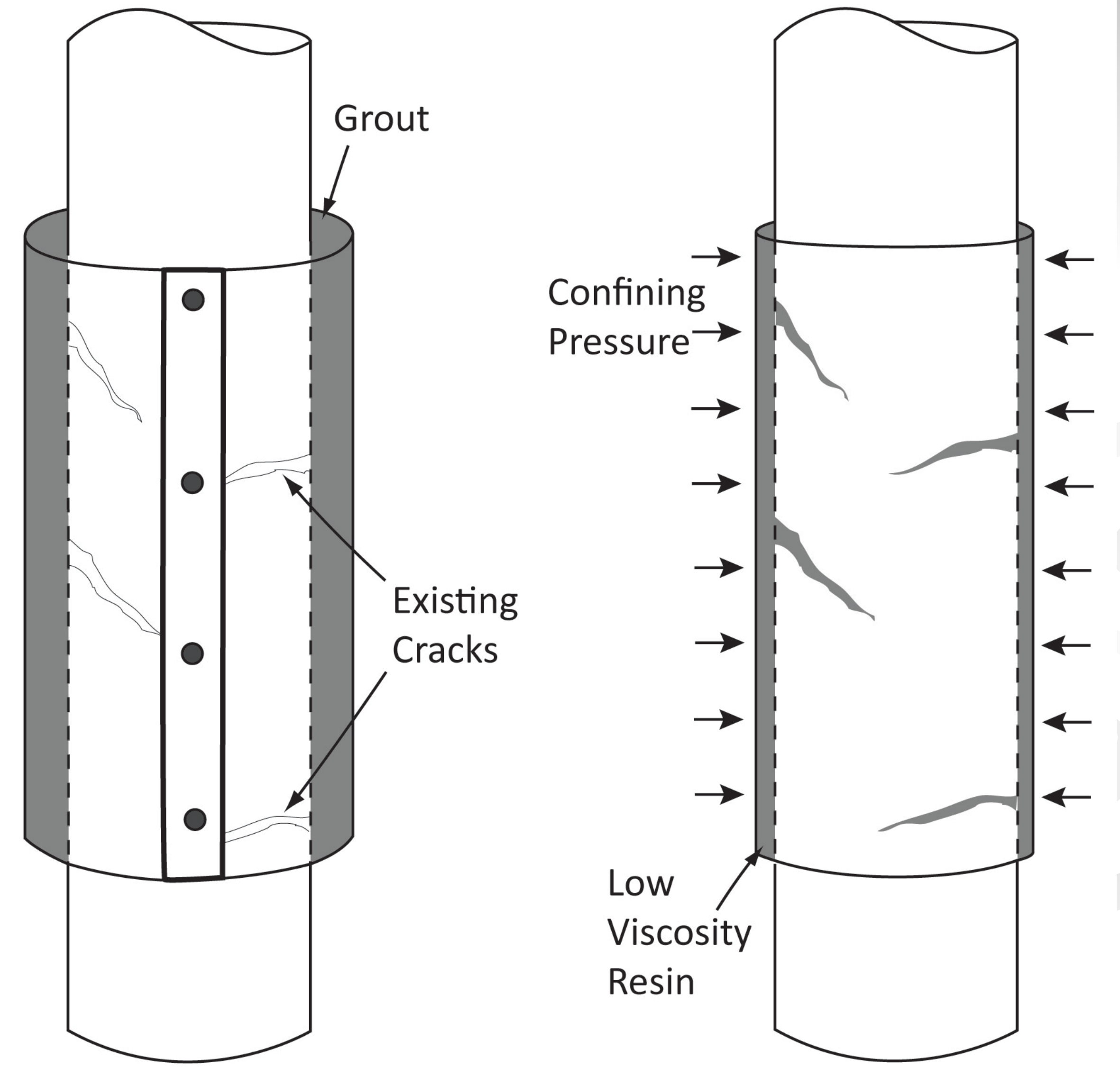
Confinement of Square Columns with SuperLaminates™



- Structural Shell
- No Finished Surface Required
- Circular or Square Columns

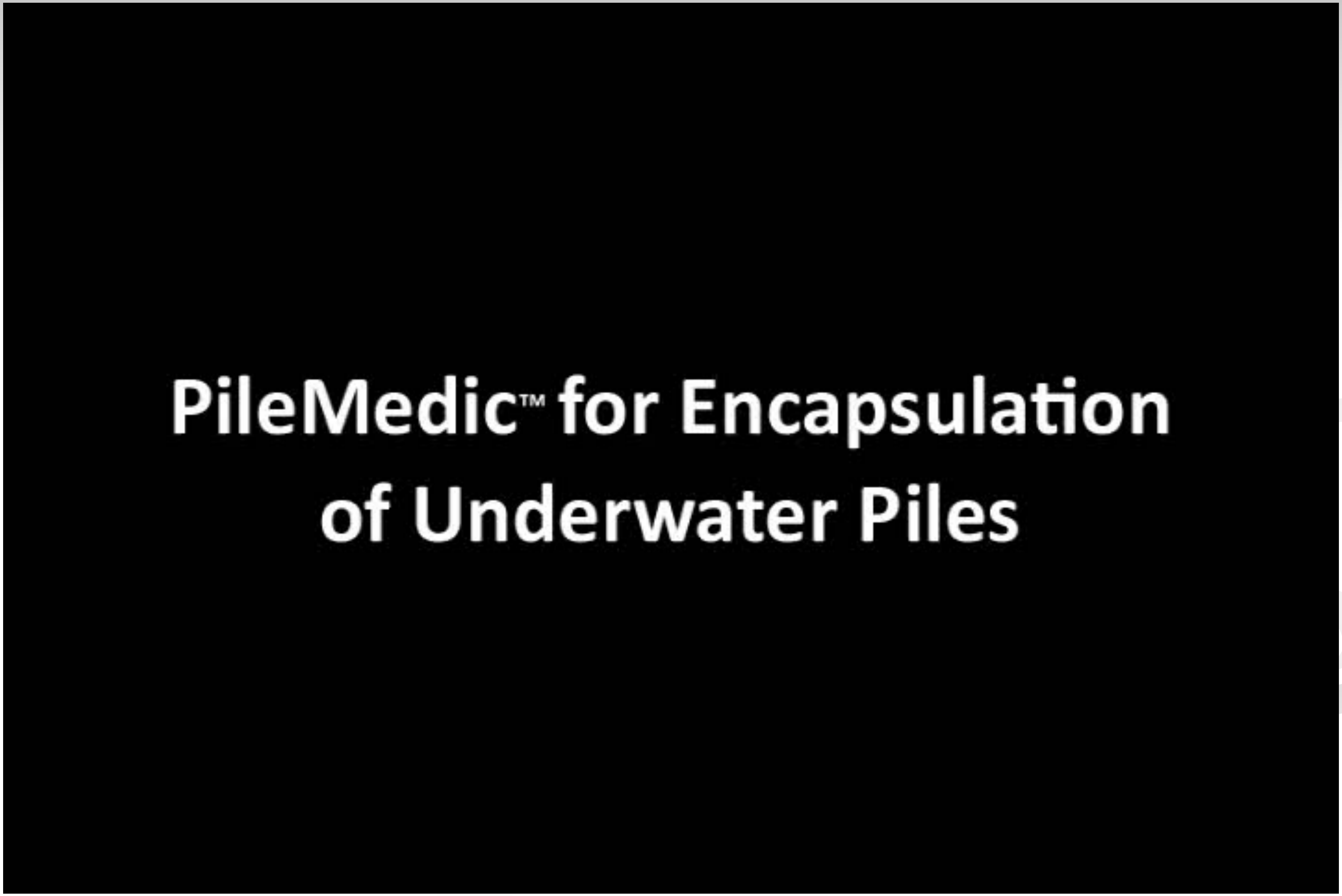
Current Pile Repair System

Conventional vs. New Jacket



Encapsulation of Underwater Piles

…*The Jacket that Fits All!*



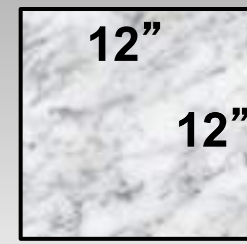
Advantages of Pile Repair Using the New System

- **No custom manufacturing – one size fits all**
- **Wraps directly around pile > Small annular space**
- **Aesthetically pleasing**
- **No metallic bolts or straps**
- **Limited or No need for costly divers**
- **No weak seams along the sides**
- **Allows pressurization of resin into annular space**
- **All voids and cracks are filled with resin**
- **Increases the strength of the pile**

Design Example

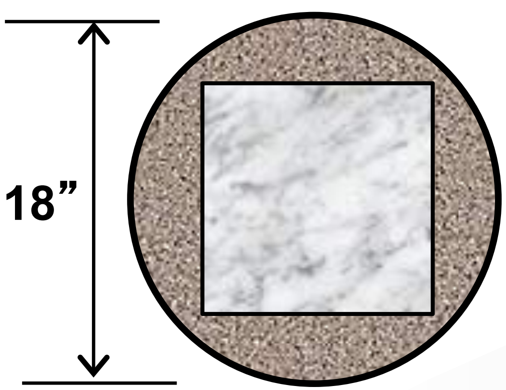
Design Data:

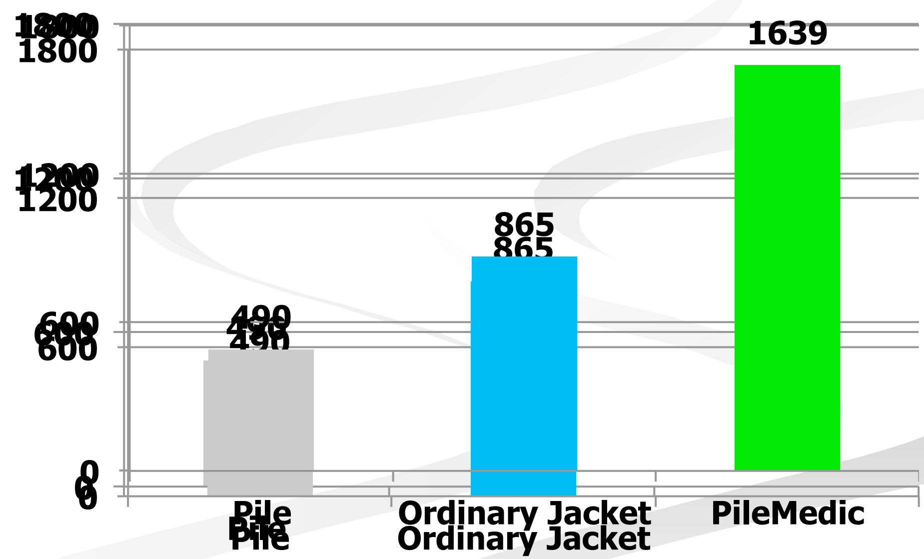
- 12x12 inch pile
- f'_c = 4000 psi
- Ignore reinforcing steel
- $P_n = 0.85 f'_c (12x12) = 490$ kips



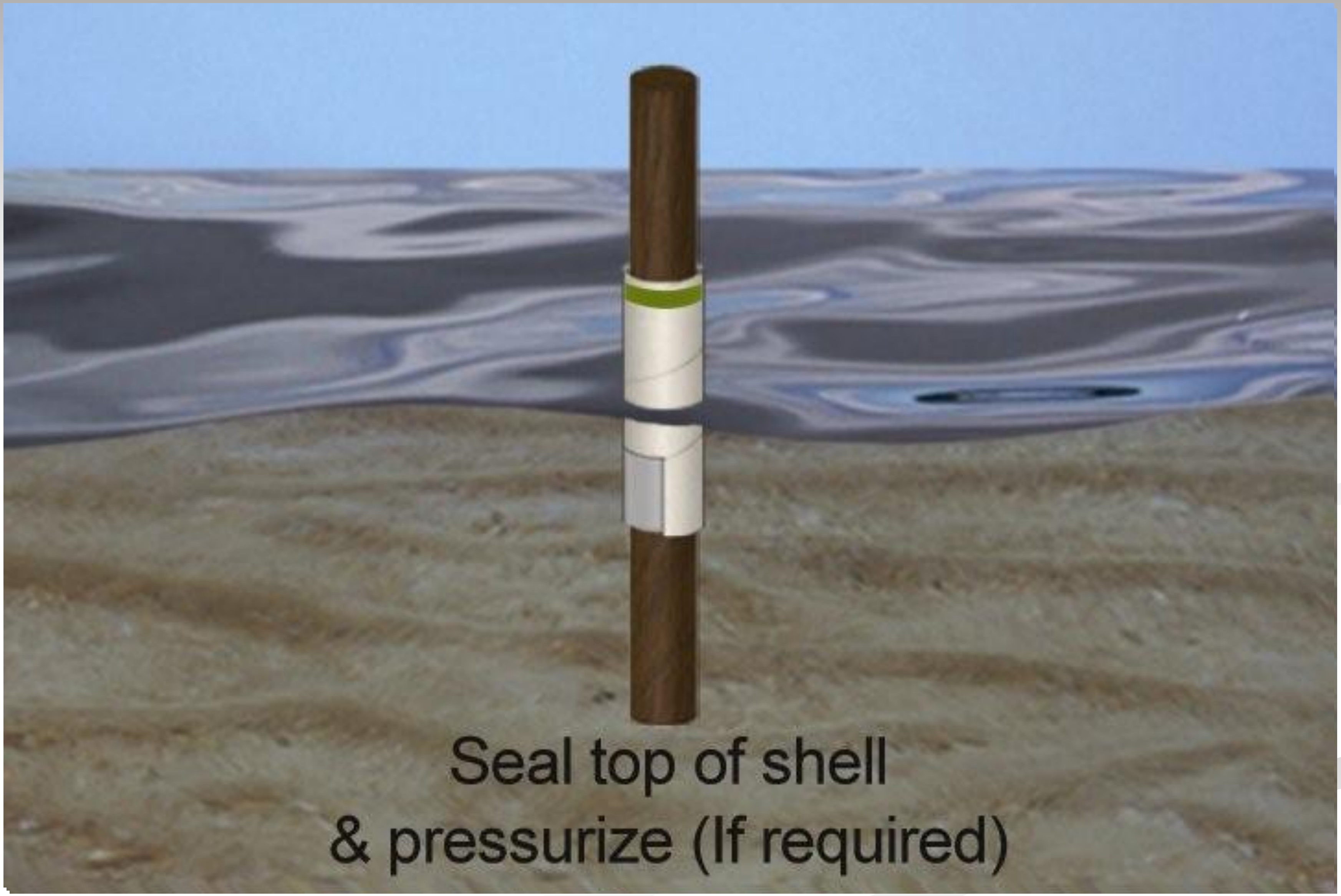
Encapsulated Pile:

- 18 inch diameter
- Fill with 4000 psi grout

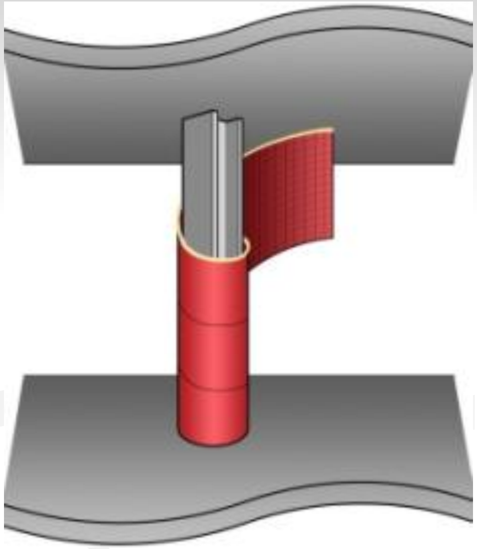




Repair of Underwater Piles

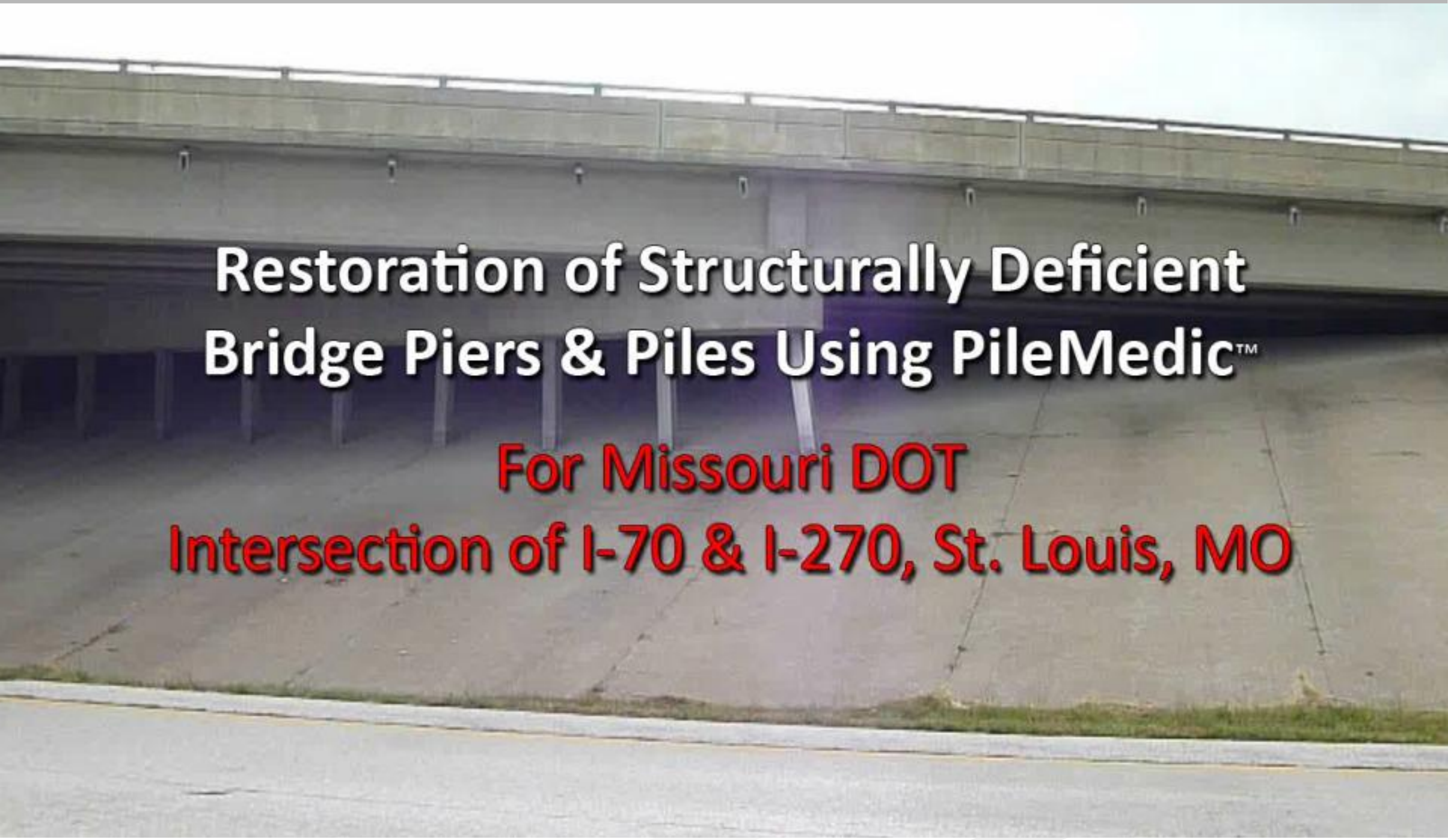


Retrofit of Steel Columns in existing frame



- Wrap laminate in a cylindrical shape around column
- Secure the top end
- Fill annular space with concrete or grout (+ Rebar)
- Can construct a composite steel-concrete column
- Increase axial & buckling load for column

Repair of Corroded Bridge Piles

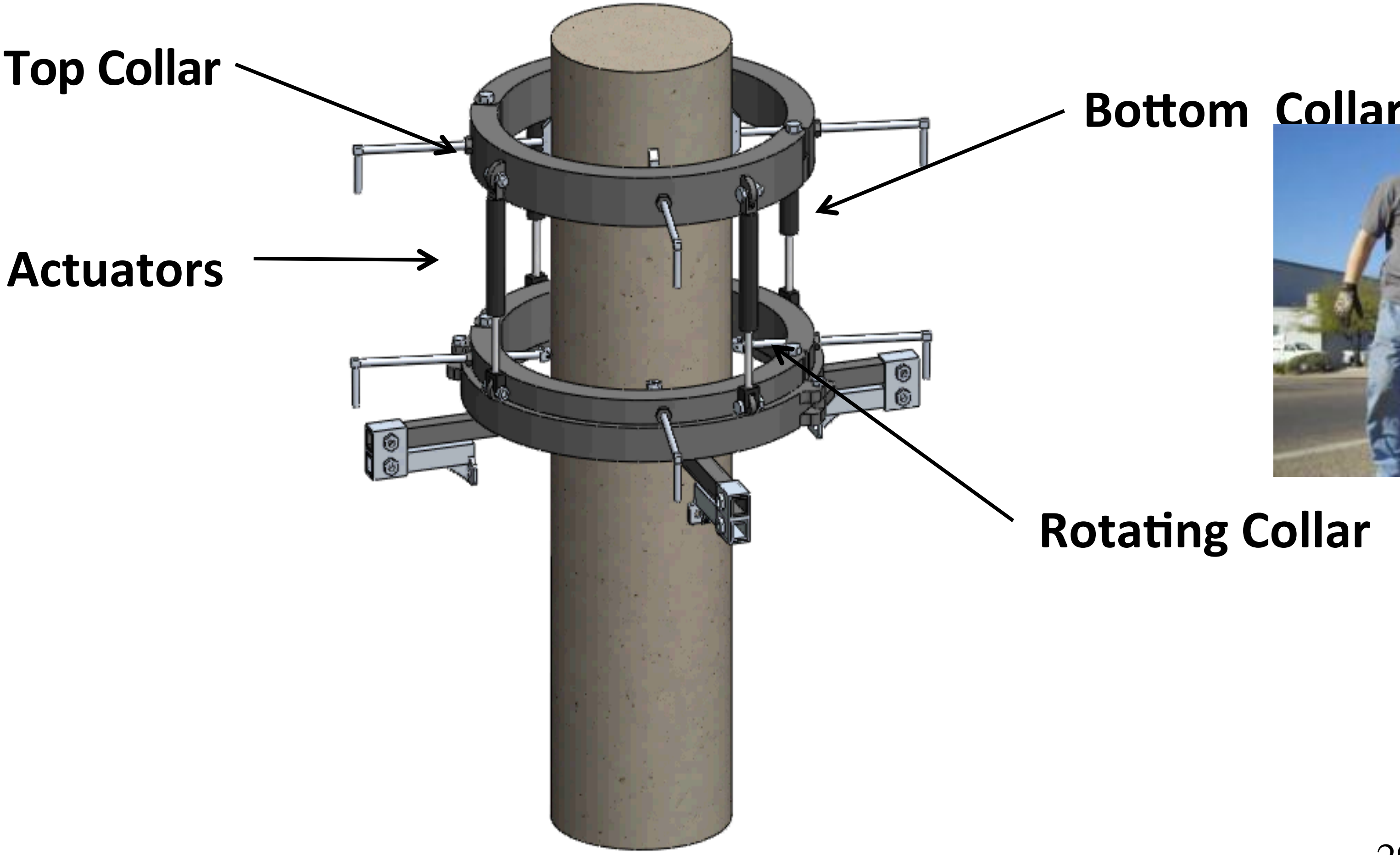


Utility Pole Repair

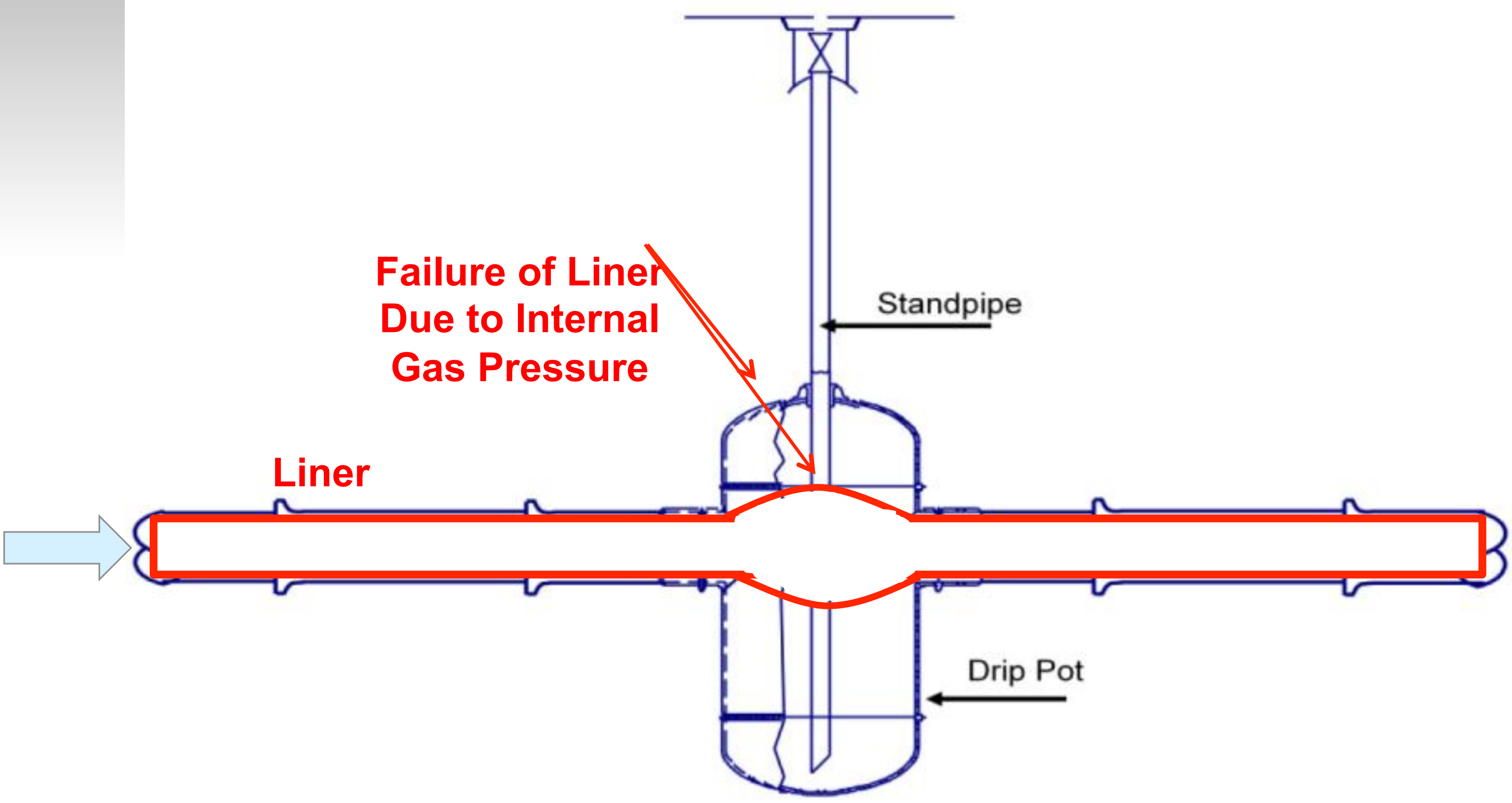
Using PileMedic
to repair a utility
pole

Robot for Repair of Utility Poles

Patent Pending



Bridging a Gap in a Pipeline
(Gas Technology Institute)



How do we create a pressurize pipe?

Bridging a Gap in a Pipeline

(24" Long Gap in 16" Diam. Pipe)

PipeMedic™ Bridges The Gap

in a Pressurized Pipe

Corrugated Metal Pipe (CMP) Culvert

- PipeMedic™ can be bonded to the high points of corrugation
- If corroded, the invert portion of culvert can be filled with self-leveling concrete.
- Advantages:
  - No loss of diameter
  - No Grouting required
  - One-Size Fits all
- Disadvantage:
  - Little Compressive Strength

Corrugated Metal Pipe Culverts

Repairing a
Corrugated Pipe
Using PipeMedic™

Thank you for your Attention!

Questions?

[*www.QuakeWrap.com*](http://www.QuakeWrap.com)

Email: Mo@QuakeWrap.com

Toll Free: (866) QuakeWrap[782-5397]