Innovative Applications of Carbon FRP in Pipelines

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Professor Emeritus of Civil Engineering, Univ. of Arizona

History

- QuakeWrap, Inc. was founded in 1994 by Dr. Mo Ehsani, Professor of Civil Engineering at Univ. of AZ
- We offer Turnkey (Engineering Design, Materials & Installation by our Crew) to repair & strengthen buildings, bridges, pipeline, etc. with Carbon Fiber Reinforced Polymer (CFRP)
- Prof. Ehsani was a pioneer in introducing these techniques in the late 1980s
- Offices in Tucson and Hermosillo, Mexico
- International clientele & projects
- Have won numerous Awards of Excellence
- Developed several patented technologies related to repair of piles and pipes, etc.

Outline

Four Technologies Related to Pipelines:

1. **Wet layup for repair of pipes**
2. **PipeMedic™ Carbon Laminates for repair of pipes**
3. **StifPipe™ Honeycomb-FRP for repair of pipes**
4. **InfinitPipe™ - an on-site manufactured pipe of any length!**

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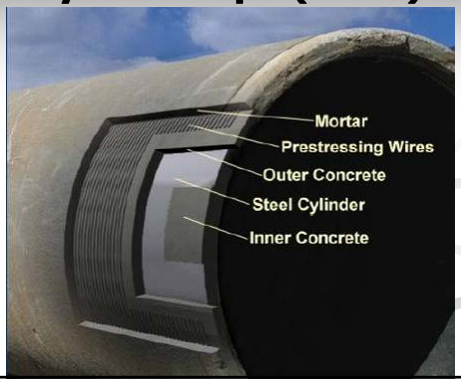
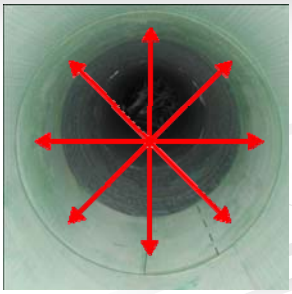
Prestressed Concrete Cylinder Pipe (PCCP)



Wet Layup Technique

- Older pipes like the one shown here fail due to corrosion of steel.
- Wet layup was introduced in 1997 and is used to repair/ strengthen such pipes
- Carbon or glass fabric is saturated with epoxy and is applied on the interior surface of the pipe (to build a new "pressure vessel" inside the old pipe).

Internal Pressure



Power Service of New Mexico (PNM)

10-ft diameter PCCP (Oct 2007)

Equipment modified to pass through access ports

Scaffolding & saturating inside pipe

Power Service of New Mexico (PNM)

120-inch diameter PCCP (Oct 2007)

Protective glass layer on steel pipe

Tight work space in 48" steel risers

Power Service of New Mexico (PNM)

10-ft diameter PCCP (Oct 2007)

- Unique Features:
  - Special Carbon Fabric Reduced Layers from 3 to 1
  - Special Pipes (openings, access ports, etc.)
  - Bends and Turns

2008 Award of Excellence from ICRI

El Encanto Hydropower, Costa Rica

1.1 miles x 84-inch diameter (July 2009)

Sloped Terrain

Water seeping into pipe

Leaks continued after cracks were filled

El Encanto Hydropower, Costa Rica

1.1 miles x 84-inch diameter (July 2009)

Four 2'x2' Access Ports

Poor surface conditions req'd much prep

El Encanto Hydropower, Costa Rica



Challenge: Not only strengthen but to leak proof
Successful pressurization tests on July 15, 2009

QuakeWrap Liner Installation Facts:

- Largest FRP penstock rehabilitation in the world completed in a single phase.
- Liner installation rate of 10,000 ft² (930 m²) a day by four installation fronts working 8 hour daily shifts allowed for more than 150,000 sq. ft. of liner to be installed in 15 days.
- Liner designed to maximize water tightness and to provide additional hoop and longitudinal structural strength to account for on going corrosion damage due to seepage water intrusion through exterior surface cracks, increasing the useful life of the penstock.

QuakeWrap Liner Installation: Facts … *continued*

- Liner will require no maintenance.
- Total shutdown period for penstock was 3 weeks, which is within the typical period allocated for programmed maintenance shutdowns in US power plants.
- Penstock successfully re-pressurized in July, 2009 and it is now in full service.
- Project received Honorable Mention in the 2009 Trenchless Technologies Project of the Year Award.
- Int'l Concrete Repair Inst. (ICCI) Award of Merit, 2010

Steel Pipes for Hot Air, Carlsbad, CA

42" curved pipe (August 2011)




Steel Pipes for Hot Air, Carlsbad, CA

36" pipe (August 2011)

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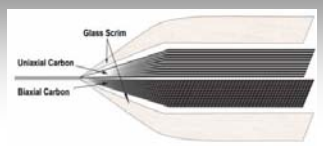
PipeMedic™ *(Patent Pending)*



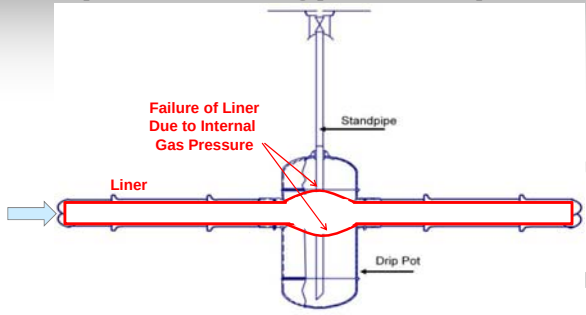
- Layers of carbon and glass are pressed together in our plant to manufacture solid laminates as shown here
- Thickness ≈ 0.01 -0.025 inch
- Tensile Strength ≈ up to 155,000 psi
- These laminates are inserted into a pipe (like a stent) using a balloon-like carrier (called packer)

Small Diameter Pipe Repair

https://www.youtube.com/watch?v=Zz7A_MQdwm8

Gas Pipeline Failure
(San Bruno, CA Sept 2010)

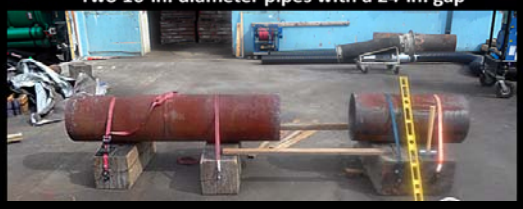
Bridging a Gap in a Pipeline
(Gas Technology Institute)



How do we create a pressurized pipe?

Bridging a Gap in a Pipeline
(24" Long Gap in 16" Diam. Pipe)

Two 16-in. diameter pipes with a 24-in. gap



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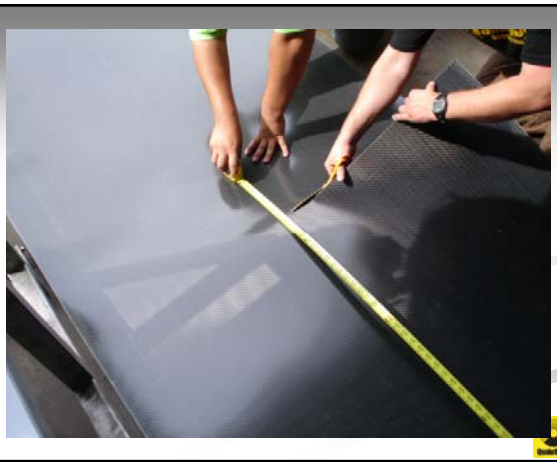

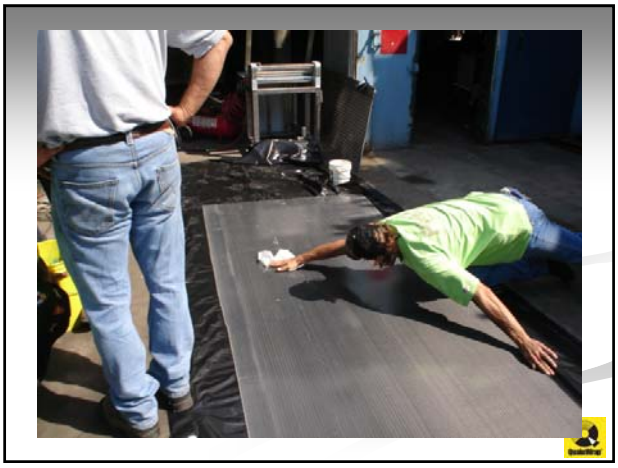

Pressure Testing

on October 16, 2010

- Gas Technology Institute
- Max Operating Pressure = 60 psi (4.1bar)
- Tested to 250 psi (17.2 bar)
- Ultimate Capacity = 900 psi (63 bar)

Field Application of PipeMedic™

- First Project was completed in Feb 2011
- Client: PSE&G (NJ Gas Utility)
- Contractor: Progressive Pipeline Management
- 2-ft gap in 16" cast-iron pipe
- Winner of ……..
  2011 Trenchless Technology *Project of the Year Award*
- *Since then we have done a dozen such projects with PSE&G*

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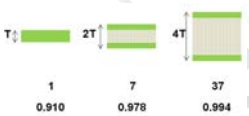
StifPipe™ *(Patent Pending)*

- Culverts and other "stand-alone" pipes require linings that are strong in compression.
- Using many layers of carbon to build such liners becomes cost-prohibitive
- We developed the StifPipe technology in 2011
- Similar to construction of an I-beam
- Instead of building a solid pipe wall with expensive carbon fabric, use a lower cost honeycomb core and apply the carbon fabric to the skin only
- StifPipe can be made to any shape or size
- The advantages of honeycomb construction is shown below:



RELATIVE STIFFNESS	1	7	37
WEIGHT (Pounds/ft²)	0.910	0.978	0.994

Manufacturing Process




Manufacturing Process ... *cont'd*



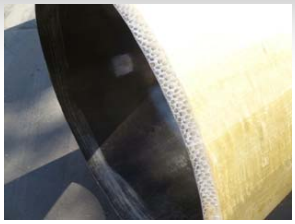

Manufacturing ... *cont'd*




StifPipe™ Installation


- Sections are custom-manufactured in advance to match size & strength requirements
- Pipe weighs < 1.5 lb/ft² (nearly 10% of most pipes)

StifPipe™ Installation

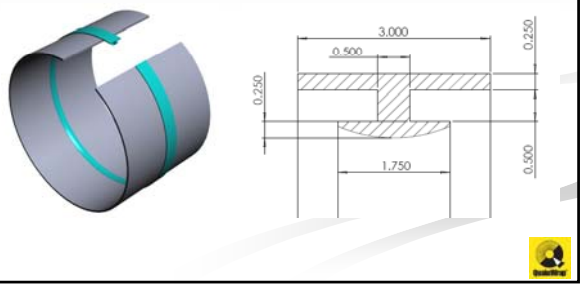



- Ends are beveled for field connection
- Overlapping fabric is sealed in field with epoxy

StifPipe™ Installation


- Overlapping fabric is sealed in field with epoxy to create a smooth joint
- Annular space is grouted

StifPipe™ Connection Detail



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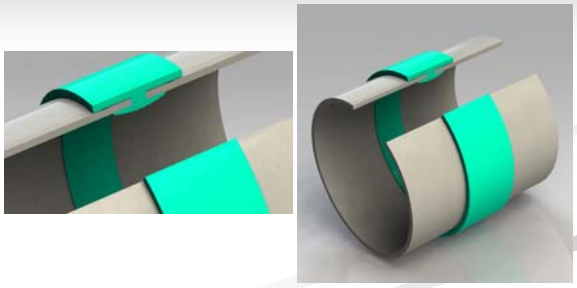

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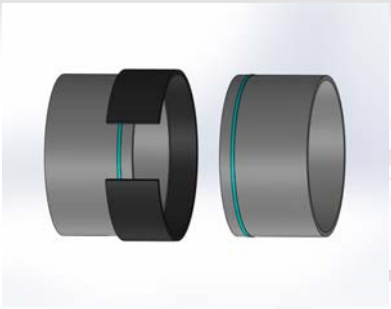
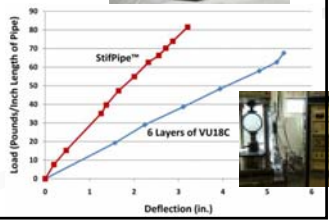


StifPipe™ Testing
at Texas Research Institute (TRI)

Case Study to Show Advantage of StifPipe compared to wet Layup

Case Study:
5850 ft x 36 in. PCCP
Design > 6 layers of CFRP
Alternative Design:
StifPipe™ with 1 layer of glass on both faces

Tested to compare stiffness
Stiffness Ratio = 2.1



Installation for 6 Layers of Carbon Fabric

- **Saturate the 2-ft wide rolls of fabric outside the pipe**
- **Deliver the fabric to the crew inside the pipe; this may include 1000 feet or more of travel depending on the location and number of access points**
- **Crew will apply the fabric to the pipe**
- **Crew must make sure that the fabric is smooth and that no air bubbles exist**
- **Repeat above procedure 6 times for 6 layers of carbon**
- **Each day, samples of saturated carbon fabric will be prepared as witness panels that will be sent to a laboratory for testing; if the test results fail, remedial action must be taken, which may cause significant delay in the project.**

Installation for StifPipe™

- Make a mandrel matching the size and shape of the pipe
- Manufacture 3-ft or longer (depending on access size) pieces of the pipe in advance and allow them to cure
- Transport the StifPipe™ sections into the pipe and position them along the pipe one next to the other
- Seal the overlapping joint between the StifPipe sections
- Fill the small annular space between the StifPipe™ and the host pipe with resin

StifPipe vs. Wet Layup Case Study

Retrofit of 5850 ft of 36-inch PCCP
55,000 sq. ft of pipe surface

	Conventional	Honeycomb FRP
Layers of Fabric	6 carbon	2 carbon + Core
Built	completely inside	Off-site; Assembled inside
Man-Hours to Complete	20,500	3,000
Contract Amount	$6.5M	$2.5M

Brooklyn Bridge Park Project

Corrugated Metal Pipe Culvert
54 in wide x 40 in. high

- Repair Options:
- Dig & Replace
- Insert a 36" steel pipe and grout (40% capacity loss)
- Use honeycomb pipe & grout (<5% capacity loss)

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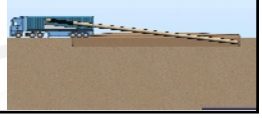
InfinitPipe™ *(Patent Pending)*

- *InfinitPipe*™ was introduced in 2012 and is an extension of the StifPipe technology.
- Like StifPipe, we can manufacture the pipe on site by:

1. Use a 20-ft long mandrel of the same diameter as the pipe
2. Wrap a couple of layers of carbon fabric around the mandrel
3. Wrap a honeycomb core around the mandrel
4. Wrap a couple layers of glass fabric around the honeycomb
5. Allow the epoxy to cure for 30 minutes
6. Partially collapse the mandrel and move it out by 18 ft.
7. Expand the mandrel to its original diameter
8. Repeat the process (go to Step 2 above)

- This results in an infinitely long pipe!
- Currently we can build this pipe by hand (manually)
- The automated manufacturing unit is being designed now & will fit in a truck



PileMedic™ *(Patent Pending)*

- *PileMedic*™ was introduced in 2010 for repair of columns & piles

Thank you for your Attention!

Questions?

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