Outline

1. Introduction, fundamentals of FRP
2. Wet layup using carbon fabric or fiberglass
3. StiffPipe®: wet layup or slip-lining repair using 3D core fabrics, Winner of 2016 ASCE Innovation Award
4. SuperLaminate®: laminated segmental repair for small diameter pipes
5. InfinitPipe®: A jointless FRP pipe made on site.
6. Q&A

Fiber Reinforced Polymer (FRP)

- A Polymer (i.e. epoxy, vinyl ester, etc.) that has been reinforced with a Fiber (e.g. carbon, glass, etc.)
- FRP is non-homogeneous.
- FRP does not have the same strength in all directions; these types of materials are called anisotropic.

σ vs. ε for Steel & Composites

<table>
<thead>
<tr>
<th>Material</th>
<th>Stress (ksi)</th>
<th>Stress (MPa)</th>
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</thead>
<tbody>
<tr>
<td>Steel</td>
<td>50</td>
<td>343</td>
</tr>
<tr>
<td>Glass FRP</td>
<td>150</td>
<td>1034</td>
</tr>
<tr>
<td>Carbon FRP</td>
<td>100</td>
<td>689</td>
</tr>
</tbody>
</table>

History of FRP

- 1980s: Studying repair of corroded beams and columns
- 1987: Use nonmetallic Carbon or Glass FRP
  - But the materials were used by the military & expensive
- 1989: Fall of Berlin Wall & drop in carbon prices
- 1989: Loma Prieta EQ in California & collapse of columns (mag = 6.7)
- Wrap columns with carbon FRP ......

How it all started ...

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Original Concept Demonstration

Carbon FRP instead of reinforcing steel

To watch this video, click on:
http://www.youtube.com/watch?v=GHKmwT/CigwY

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Design of Pipes with FRP

Carbon Fabric

Thickness: 0.05 in.
Weight: 0.38 lb/ft²
T = 6000 lb/in.

P = (6,000+6,000)/24 in. = 500 psi (34.5 bar)
P = (12,000+12,000)/24 in. = 1,000 psi (69 bar)

Note: Little change in weight or thickness

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Sample Projects/Applications

Testing + R&D
Condo, FL
Submerged Piles, Nigeria

Bridge, NM
Settling Tank, MX
UN Lebanon
Corroded STL Columns
Kazakhstan

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Research & Development

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Organization

QuakeWrap®
(PipeMedic, PileMedic)
Engineering, Materials
R&D, Manufacturing

FRP Construction
Other Contractors

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Methods of Pipeline Rehab

- Dig and Replace
  - Pros – use of conventional materials
  - Cons – disruptive, expensive
- Trenchless Techniques
  - Pros – no excavation required, lower social cost, lower carbon footprint
  - Cons – quality of installation is critical

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**Advantages of FRP for Repair of Pipelines**

- High tensile strength (2-4 times that of steel)
- Anisotropy allows efficient use of materials (e.g. hoop vs. longitudinal)
- Non-corroding
- Water-tight membrane
- Fits all shapes & sizes
- Some manufacturers meet NSF-61

**Hoop and Longitudinal Stress**

**Wet Layup Process**

- Paloverde Nuclear Power Plant, AZ
- Prestressed Concrete Cylinder Pipe (PCCP)
- Corrosion of pre-stressing cables
- Design to internal pressure
- Replacement recommended
- CFRP liner installed
- 108-inch (2700mm) Diameter
DC Water – 96-inch Sewer Repair

Sloped Terrain

Water seeping into pipe

Leaks continued after cracks were filled

El Encanto Hydropower, Costa Rica

1750m x 2.1m diameter (July 2009)

Sloped Terrain

Water seeping into pipe

Leaks continued after cracks were filled

Mormon Flat Dam (SRP), Arizona

Riveted Steel Penstock (January 2015)

- Corrosion of steel
- Loss of thickness
- Loss of Strength
- Challenging access through winding road
- Challenging Geometry
  - Two 96-inch pipes
  - One 120-inch pipe
  - 20 feet vertical drop
- Consultants had suggested replacement
- Owner decided to repair with CFRP

Salt River Project - Penstock Construction

Typical Design Details

- Glass FRP as dielectric barrier
- Carbon FRP Layers:
  - 120": 3H + 2L
  - 96": 2H + 1L
- Overlap Details
- Termination Detail
Salt River Project – contd.

Lake Lure Dam, North Carolina
Riveted Steel Penstock (January 2020)

- Complex geometry
- Surface prep
- Primer applied

Lake Lure Dam, North Carolina
Riveted Steel Penstock (January 2020)

- Abrasion-Resistant
- Weko Seal
- Completed installation

3D Drawing/Modeling

PCCP Rehab Design Drawing

PCCP Rehab Termination Point
City of Atlanta - Clayton Plant (2016)

Tests of Steel Pipes (5-inch Dia.)
Pertamina Oil Company, Indonesia

Test of Steel Pipe to 1300 psi (90 bar)

Wet Layup Repair of Pressure Pipe in water

Watch Video at https://tinyurl.com/tv5xmlz

Design for Thrust

- Align the fibers along the length of pipe
- Increase/decrease number of layers based on the thrust magnitude

Testing – ICC Durability

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Bond Strength</th>
<th>Pullout Strength</th>
<th>Adhesive Bond</th>
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<tbody>
<tr>
<td>APA 3000</td>
<td>1280</td>
<td>1270</td>
<td>1210</td>
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<tr>
<td>APA 3001</td>
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<td>APA 3003</td>
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<tr>
<td>APA 3004</td>
<td>1270</td>
<td>1260</td>
<td>1270</td>
</tr>
</tbody>
</table>

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Quality Control

- Record Lot #
- Adhesion Test (ASTM D7234) (200 psi min.)
- Witness Panel (ASTM D3039); 5 glass and 5 carbon FRP coupons

3) StifPipe®

Composite Sandwich Concept

Steel I-beam

ASCE 2016 Innovation Award
American Society of Civil Engineers

World’s first green & sustainable pipe!

Manufacturing Process

Field Installation
Avalon Pump Station, CA
CMP Culvert Rehab by Sliplining
(Watch Video at https://tinyurl.com/y8m9tuub)

3D – Wet Layup™

3-D FRP Built in Pipe

Case Study
Edison, NJ Sept. 2018

Minneapolis, MN I-35 Tunnel Repair
Watch video at: https://tinyurl.com/sp8fb8v

I-35 Tunnel Repair – contd.
End Terminations

Non-Circular Design

- Can be complex
- Standard design equations do not apply
- Ability to partition the design with anisotropic FRP

4) Small Diameter Point Repair

FRP Laminates

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

Bridging a Gap in a Pipeline

(600mm Long Gap in 400mm Diam. Pipe)

Watch Video at https://tinyurl.com/v9nsjyf

EPA SBIR Grant:

Trenchless Water Main Point Repairs with SuperLaminate

Watch Video at: https://tinyurl.com/stw497h
The pipe shown in the video:
- Diameter = 8 inch (200 mm)
- Thickness = 0.20 inch (5 mm)
- Weight < 2.5 pound/ft (3.5 kg/m)
- Pressure Rating > 500 psi (34 bar)
- Materials Cost ~ $7/ft