



# WELCOME

**PROF MO EHSANI**




**DR FIRAT SEVER**



**Economical Pipeline Rehab and Repair using FRP**



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## 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

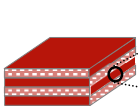
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## Fiber Reinforced Polymer (FRP)

- 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*.





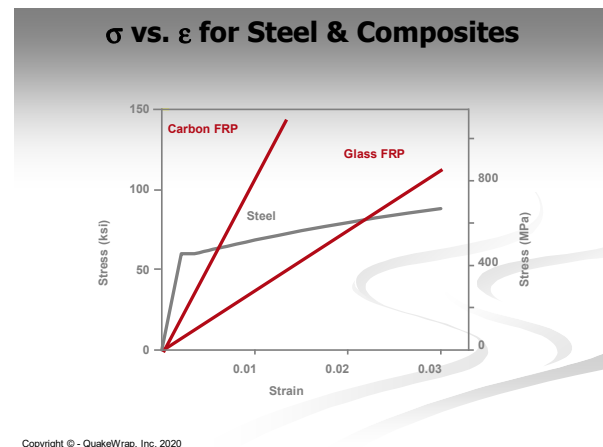
Reinforcing Fiber (Glass, Carbon, Kevlar, etc.)

Interphase Coupling Agent

Polymer Resin Matrix

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## History of FRP

**Corvette C1 - 1953**



**100% FRP Hull**





**Materials used in 787 body**

| Material                  | Percentage |
|---------------------------|------------|
| Fiberglass                | 15%        |
| Carbon laminate composite | 25%        |
| Carbon sandwich composite | 15%        |
| Aluminum                  | 20%        |
| Other                     | 5%         |

**Total materials used by weight**

Steel 15%, Composites 30%, Carbon 15%, Aluminum 20%, Other 5%

By comparison, the 777 uses 12 percent composites and 50 percent aluminum.





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## How it all started ...

- 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 .....
- QuakeWrap®







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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=GHKmw7CYgwY>

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### Design of Pipes with FRP

Carbon Fabric



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



$$P = (6,000 + 6,000) / 24 \text{ in.} = 500 \text{ psi (34.5 bar)}$$

$$P = (12,000 + 12,000) / 24 \text{ in.} = 1,000 \text{ psi (69 bar)}$$

**Note: Little change in weight or thickness**

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### Sample Projects/Applications



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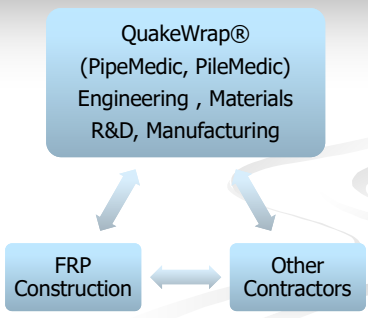
### Research & Development

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### Organization



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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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## Trenchless Technology



Coatings: Epoxy, Polyurethane, Polyurea

## CIPP – Cured-In-Place Pipe

HDPE, PVC liners

### Cementitious / Geopolymer Linings, Shotcrete

FRP – Fiber Reinforced Polymer

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## 2) Wet Layup



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## Advantages of FRP for Repair of Pipelines

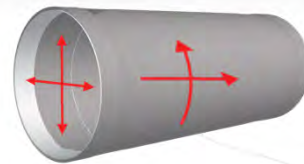
- High tensile strength (2-4 times that of steel)
- Anisotropy allows efficient use of materials (e.g. hoop vs. longitudinal)
- Non-corroding
- Water-tight membrane
- Fits all shapes & sizes
- Some manufacturers meet NSF-61



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## Hoop and Longitudinal Stress



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## Wet Layup Process



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## Early Applications in 1998

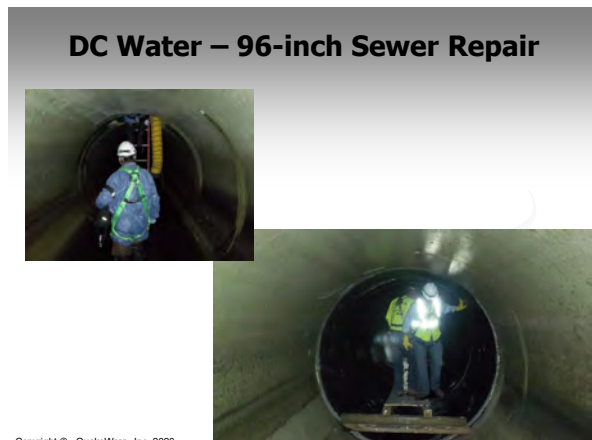
- Paloverde Nuclear Power Plant, AZ
- Prestressed Concrete Cylinder Pipe (PCCP)
- Corrosion of pre-stressing cables
- Design to internal pressure
- Replacement recommended
- CFRP liner installed
- 108-inch (2700mm) Diameter



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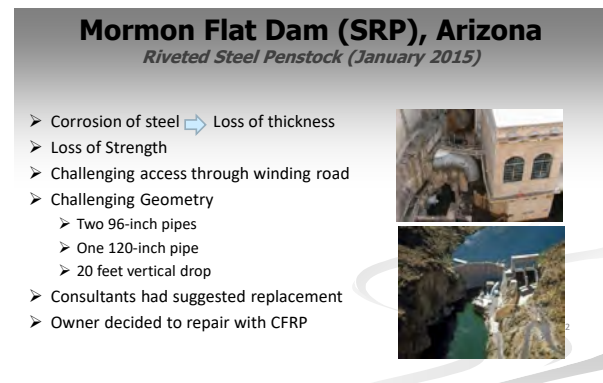
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**1.1 mile of 84-in. pipe repaired in 3 weeks  
Recognized by 2 International Awards**

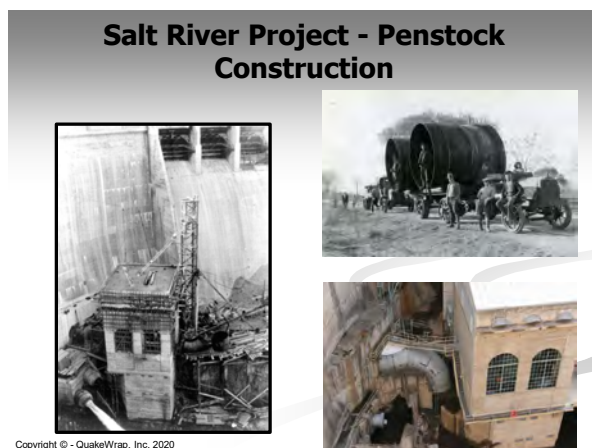
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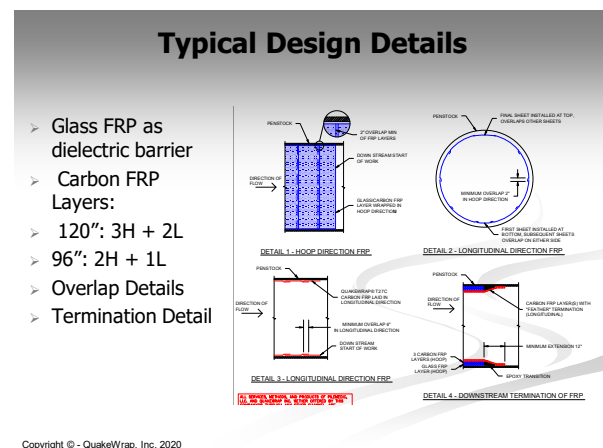
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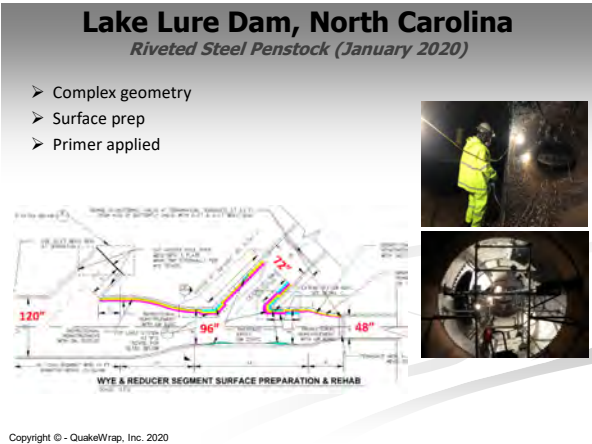
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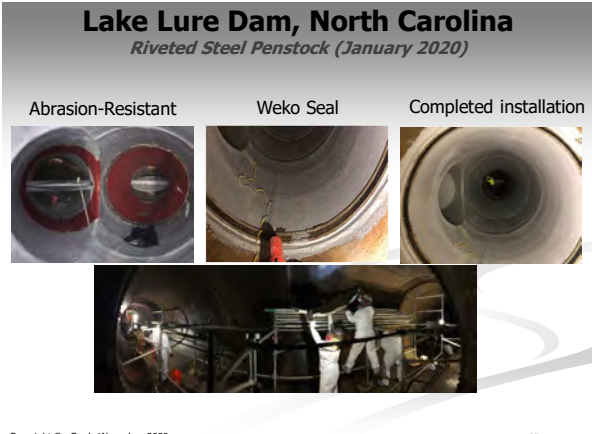




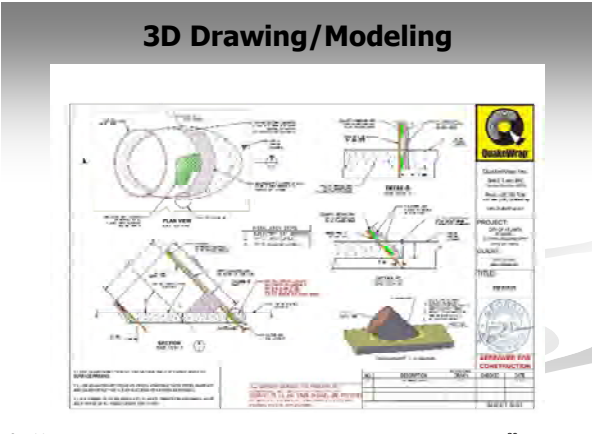
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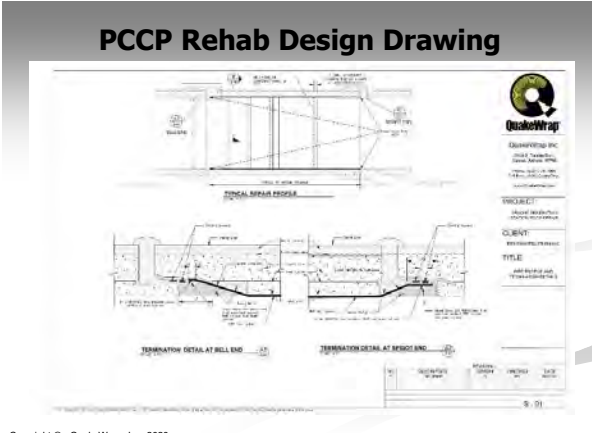
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### City of Atlanta - Clayton Plant (2016)



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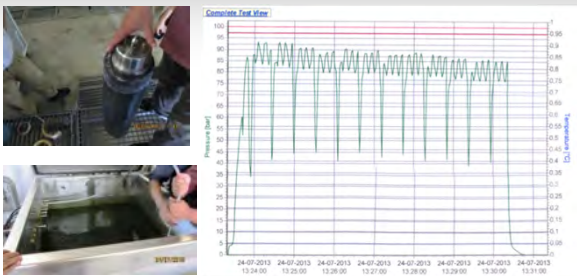
### Tests of Steel Pipes (5-inch Dia.) Pertamina Oil Company, Indonesia



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### Test of Steel Pipe to 1300 psi (90 bar)



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### Wet Layup Repair of Pressure Pipe in water

Watch Video at <https://tinyurl.com/tv5xlmzl>

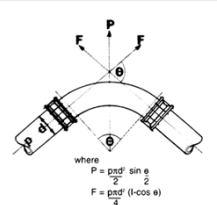


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### Design for Thrust

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




where  
 $P = \frac{\pi d^2 \sin \theta}{2}$   
 $F = \frac{\pi d^2 (1 - \cos \theta)}{4}$

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### Testing – ICC Durability



| Specimen ID        | Ultimate Strength<br>$f_u$<br>MPa | Guaranteed Strength<br>$F_u$<br>MPa | Ultimate Strain<br>$\epsilon_u$<br>% | Guaranteed Strain<br>$\epsilon_u$<br>% | Modulus of Elasticity<br>$E$<br>GPa | Modulus of Elasticity<br>$E$<br>Msi |       |       |
|--------------------|-----------------------------------|-------------------------------------|--------------------------------------|--|-------------------------------------|-------------------------------------|-------|-------|
| QUA_U20C_TNS-00_CC | 1215.4                            | 1215.4                              | 1010.0                               | 146.9                                  | 1.28                                | 0.94                                | 95.1  | 13.80 |
| QUA_U41C_TNS-00_CC | 1276.1                            | 1276.1                              | 1054.5                               | 152.9                                  | 1.28                                | 0.99                                | 100.1 | 14.53 |
| QUA_B20C_TNS-00_CC | 1173.4                            | 1173.4                              | 1001.6                               | 145.3                                  | 1.85                                | 1.47                                | 63.6  | 9.22  |
| QUA_B20C_TNS-80_CC | 1076.0                            | 1076.0                              | 891.8                                | 129.3                                  | 2.02                                | 1.57                                | 63.5  | 7.76  |

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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



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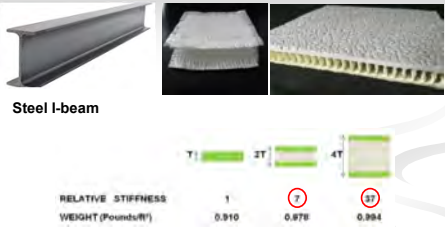
### 3) StifPipe®



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### Composite Sandwich Concept



|                    | 1     | 2     | 3     |
|--------------------|-------|-------|-------|
| RELATIVE STIFFNESS | 1     | 0.978 | 0.984 |
| WEIGHT (Pounds/Ft) | 0.910 | 0.878 | 0.984 |

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### ASCE 2016 Innovation Award

*American Society of Civil Engineers*



**World's first green & sustainable pipe!**

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### Manufacturing Process




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### Field Installation

*Avalon Pump Station, CA*



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### CMP Culvert Rehab by Sliplining

(Watch Video at <https://tinyurl.com/y8m9tuub>)



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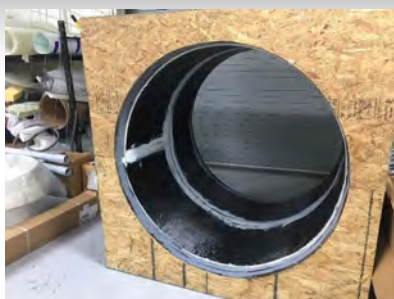
### 3D – Wet Layup™



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### 3-D FRP Built in Pipe



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### Case Study

Edison, NJ Sept. 2018



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### Minneapolis, MN I-35 Tunnel Repair

Watch video at: <https://tinyurl.com/sp8fb8v>



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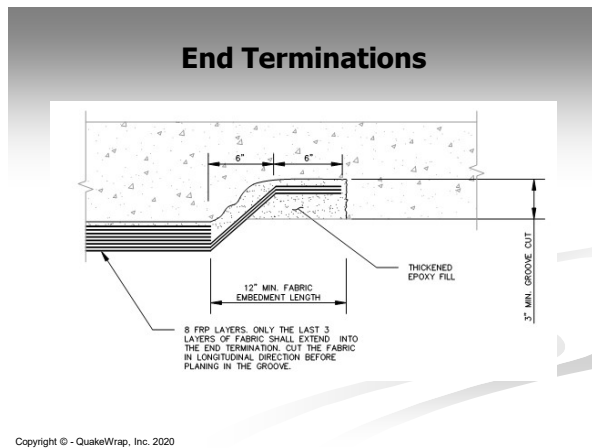
### I-35 Tunnel Repair – contd.



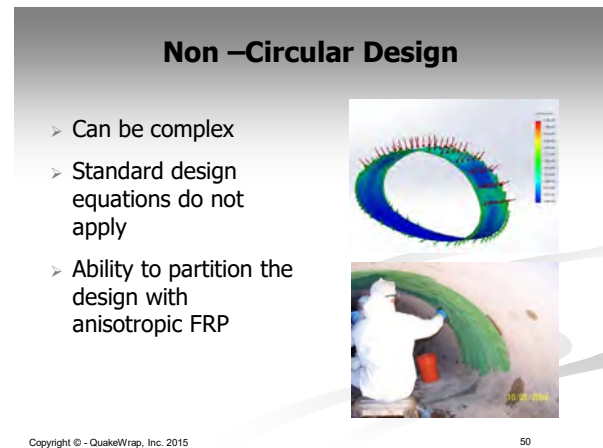
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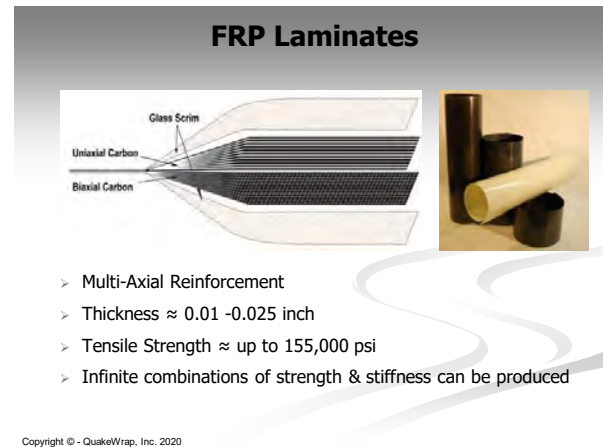
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**Onsite-Manufactured InfinitPipe®**  
 Watch Video at: <https://tinyurl.com/rx4wj75>



**InfinitPipe®: On-Site Manufactured Pipe**


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



October 2014

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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

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\*Attendees receive a certificate for 1.0 PDH in states where applicable

with  
 Prof. Mo Ehsani, PhD, PE, SE

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**Thank You!**




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