



# Design and Quality Assurance of CFRP Repair of Concrete Pressure Pipes

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DESIGN

INVESTIGATE

REHABILITATE



# Objective

- Outline the design approach and present QA requirements for repair of PCCP with CFRP liners.
- Introduce recent developments in the area (Draft AWWA Standard, the WaterRF Project).
- Highlight consequences of lack of proper QA.

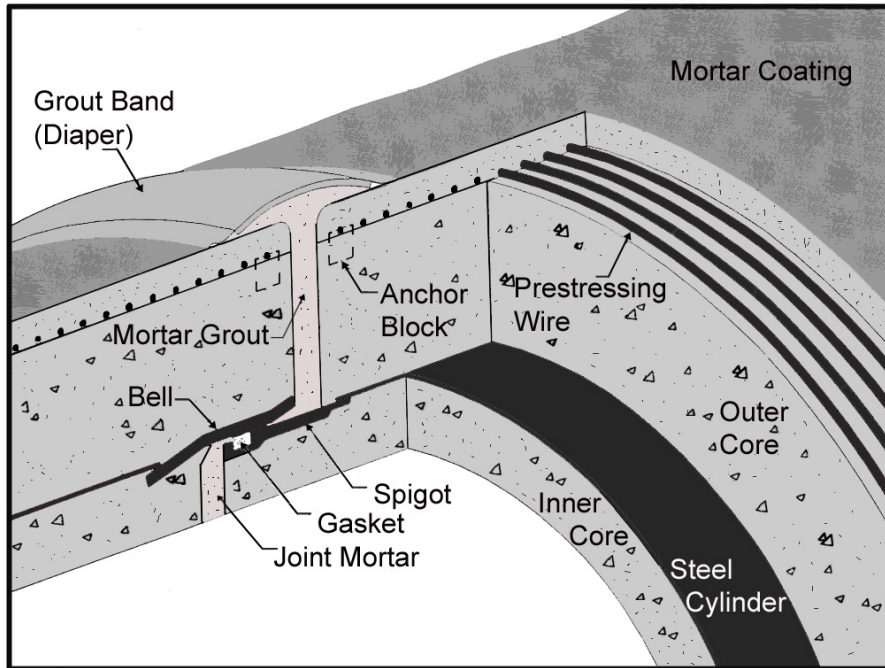


# Outline

- Introduction
- Design Criteria
- Draft AWWA Standard and the WaterRF Project
- QA Requirements (prior to, during, and after construction)
- Case Histories
- Conclusions

# Distressed Pipe

## PCCP





# CFRP Liners

- No need for external access
- >15 year track record
- Draft AWWA Standard in progress



# CFRP Design Approach

- Consider degradation level of host pipe
- Stand-alone versus composite design (with inner core)
- Use LRFD



## Circumferential Design

Limit State	Loads
CFRP Rupture	Internal pressure + External gravity loads
Buckling	External loads including Groundwater + Vacuum
Debonding	Empty pipe under external loads

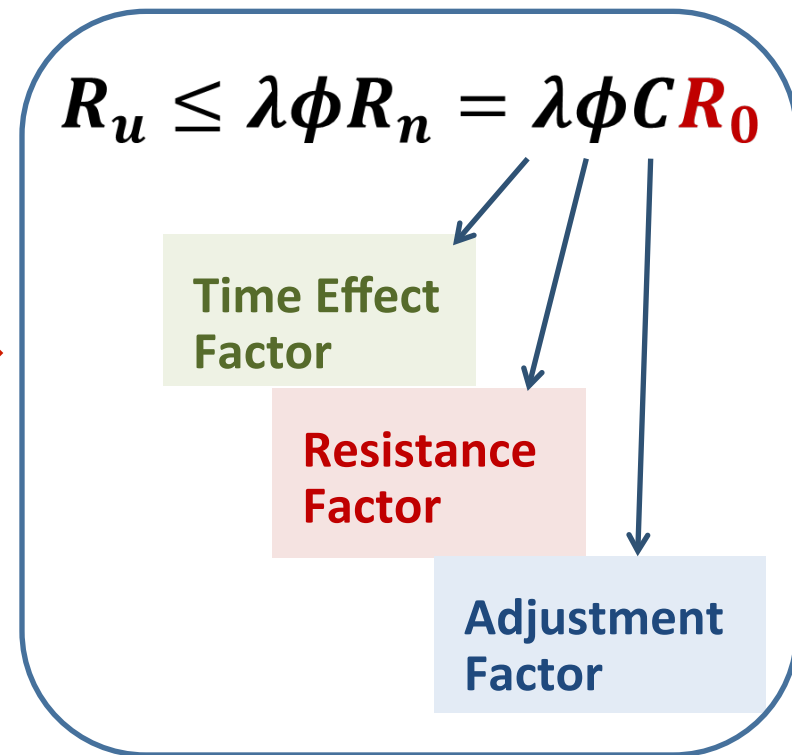
## Longitudinal Design

Limit State	Loads
CFRP Rupture	Internal pressure (Thrust, Poisson) + Temperature
Debonding	Internal pressure (Thrust, Poisson) + Temperature
Buckling	Temperature

# The WaterRF Project

Objective: Develop all necessary technical background for an LRFD-based AWWA Standard.

	Task
1	Literature Review
2	Design Requirements
3	FEA of Soil-Structure Interaction
4	Buckling of CFRP Liner
5	Constrained Soil Modulus
6	Bond Strength Test
7	Hydrostatic Pressure Test
8	Three-Edge Bearing Test
9	Reliability Analysis



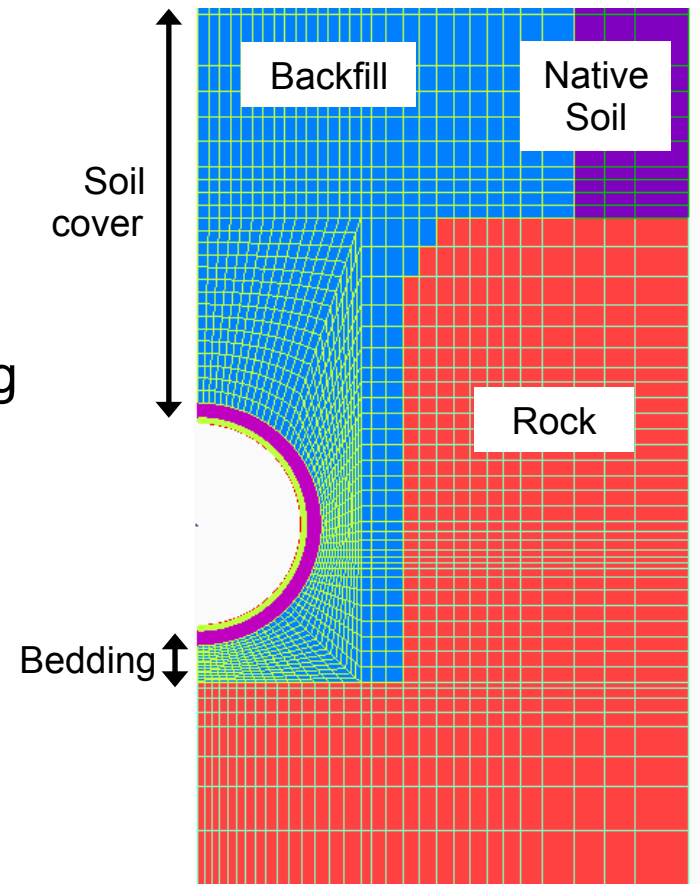
# The WaterRF Project – Analysis

## Account for:

- CFRP-pipe-soil interaction for different soils
- Installation condition
- Construction sequence
- Concrete cracking and CFRP debonding

## Determine:

- Load on pipe
- Failure pressure
- Shape factor,  $D_f$
- Rerounding coefficient,  $R_c$
- Debonding behavior





# The WaterRF Project – Testing

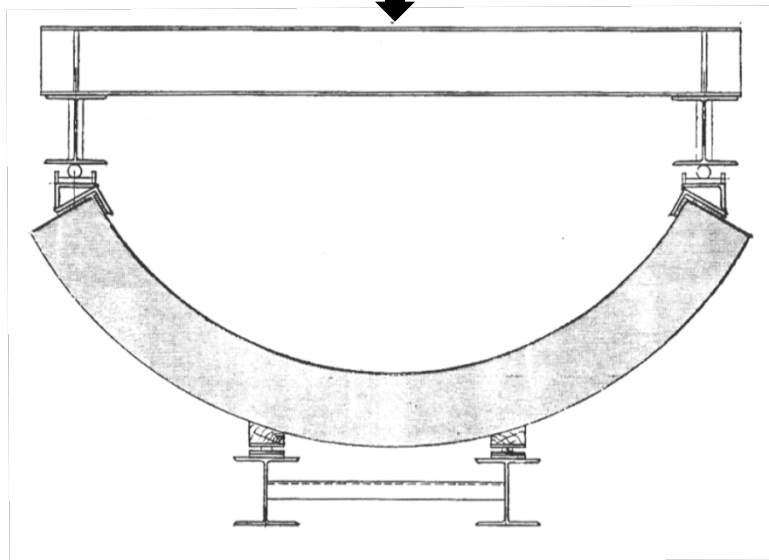
Hydrostatic



Three-Edge Bearing



Bond  
Strength



# QA Requirements

- Prior to Construction
  - Parties' Experience, Materials, Inspection
- During Construction
  - Testing, Installation, Independent Inspection, Curing
- After Construction
  - Inspection, Testing

# Involved Parties

Prior to  
Construction

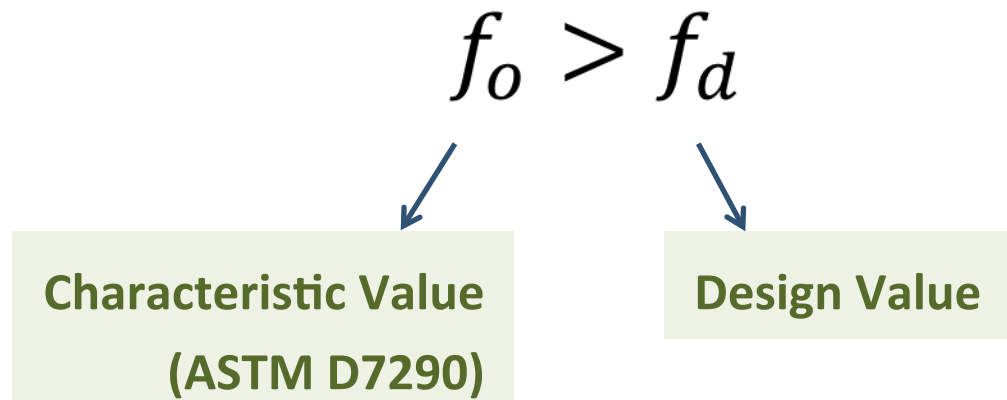
- **Owner:** Provides pipe design data and design loads (working and transient pressure, vacuum, live, etc.)
- **Engineer:** Designs repair, responsible for QA/QC of repairs.
- **Manufacturer:** Supplies a complete CFRP repair system. Must provide all required material data and supporting test results and installation guidance, and must license and train installers.
- **Installer:** Installs CFRP according to drawings and specifications; qualified by manufacturer and experienced in confined space installation of CFRP.
- **Special Inspector:** Engineer's representative who monitors and documents all phases of construction for compliance with repair drawings and specifications and directs corrective actions.
- **Testing Agency:** Qualified testing laboratory independent from the Installer.

# Laminate Qualification

## Short-term

Property	ASTM Test Method	Min. No. of Tests
Longitudinal tensile strength and modulus	D3039	10
Longitudinal compressive strength and modulus	D6641	10
Longitudinal flexural strength and modulus	D790	10

*Engindeniz et al. 2011*





# Laminate Qualification

## Durability

Durability Test	ASTM Test Method	Test Condition	Test Duration (hrs)	Min. No. of Tests	Required % Retention of Characteristic Tensile Properties
Water resistance	D2247 E104	100% RH, $\max(T_{\max}^{(2)}, 125^{\circ}\text{F})$	1,000	10	90%
			3,000	10	85%
			10,000	10	80%
Temperature resistance	D3045	$\max(T_{\max}^{(2)}, 125^{\circ}\text{F})$	1,000	10	90%
			3,000	10	85%

<sup>(1)</sup> This table should be extended as necessary to include all environmental conditions defined by the Owner (e.g., exposure to sea water, sewage, chemicals).

<sup>(2)</sup>  $T_{\max}$  = maximum operating temperature defined by the Owner.

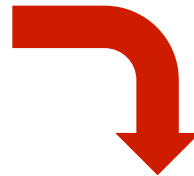
*Engindeniz et al. 2011*

## Creep Rupture

$$(f_{SL})_{50} > 0.60 f_{ST}$$

# Resin Qualification

- Primer
- Tack Coat
- Thickened Epoxy
- Impregnating Resin
- Top Coat



- $T_g > T_{max} + 40^\circ\text{F}$
- Long-term water absorption <2%
- Curing performance documented with test data
  - Temp. vs. % cure
  - % cure vs. hardness
- NSF 61 compliance
- No VOC

# Inspection of Host PCCP

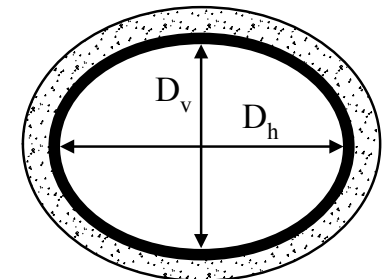
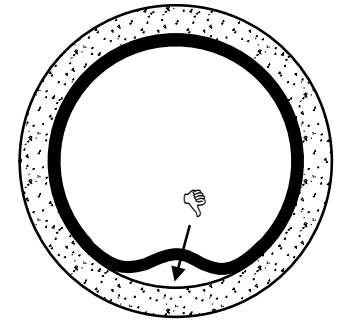
## Identify:

- Cracks
- Surface irregularities (waviness imperfection)
- Ovality (another imperfection)
- Quality of inner core concrete



## Affects:

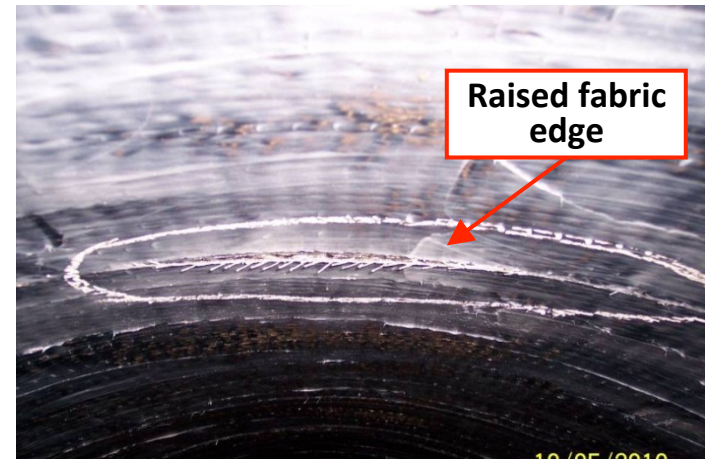
- Design approach (standalone vs. composite)
- Surface preparation
- Buckling strength of CFRP liner
- Special details at cracks



# Independent Inspection

**During  
Construction**

- Engineer's or Owner's representative
- Full time
- To verify all construction activities, including:





# Independent Inspection

- Condition of host pipe
- Surface preparation (minimum ICRI CSP3 required)
- Testing of mockup panels (bond strength) for onsite verification of construction quality
- Material storage, preparation, and application
- Application (details, timing)
- Control of air flow, temperature, and humidity
- Termination details
- Preparation of witness panels
- Post-installation inspection
- Curing (85% cure before service)

# Mockup Panel Testing

- Minimum (3) 2 ft x 2 ft panels
- Prepared and tested by Installer (ASTM D4541)
- Witnessed by Inspector
- >200 psi required for at least 3 tests per panel
  - Failure mode may affect design approach!





# Installation

**(1) Prepare Surface**



**(2) Apply Primer**



**(3) Apply Tack Coat and Thickened Epoxy**



**(4) Impregnate Carbon Fabric**



**(5) Lay Fabric**



**(6) Apply Top Coat**

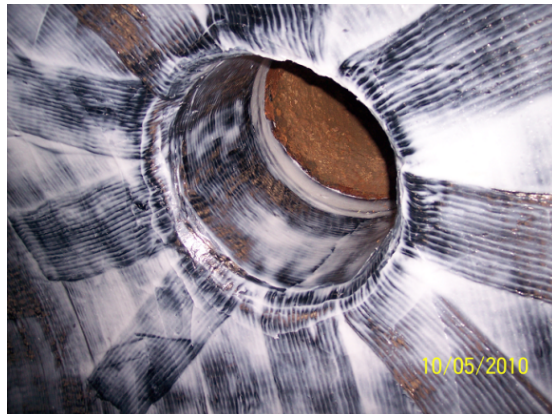


# Special Details

## End Termination Detail



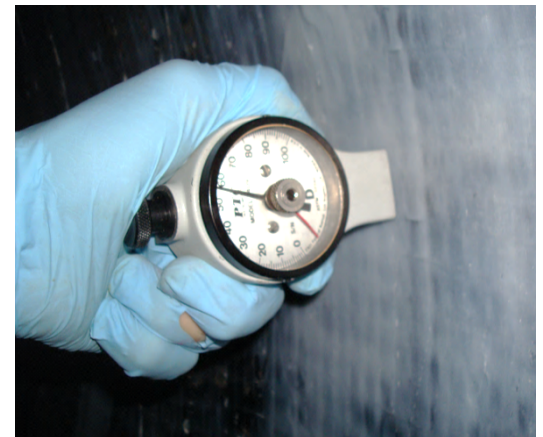
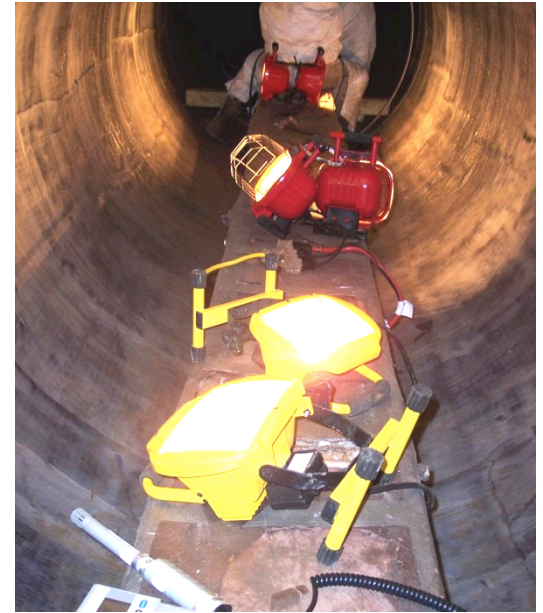
## Outlets





# Curing

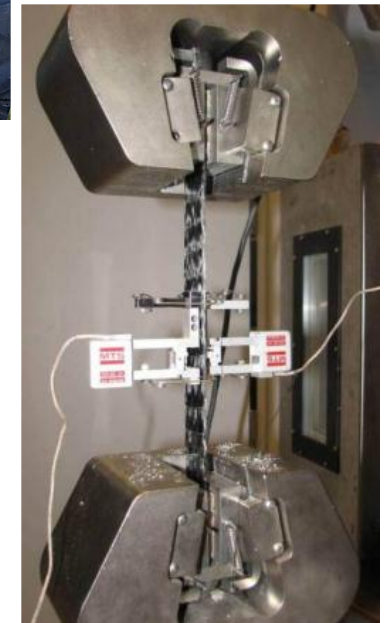
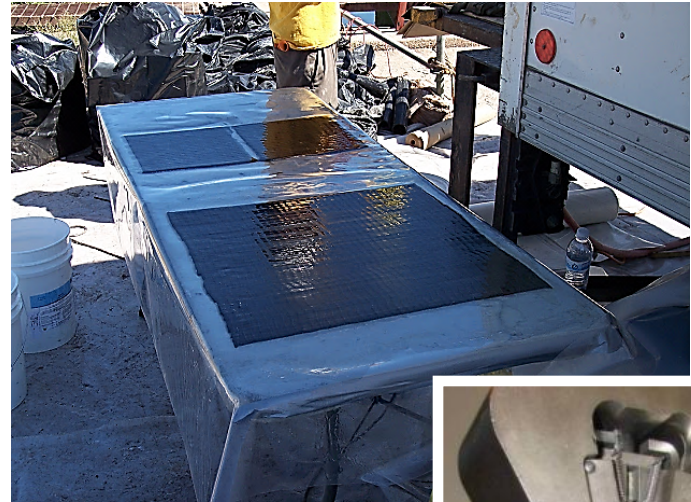
- **>85% cure required prior to refilling the pipeline**
  - Proper work schedule
  - Curing temperature and duration (consider elevated temperature)
- **Confirm with test data provided by Manufacturer**
  - Temperature vs. % cure
  - % cure vs. hardness (Shore D or Barcol)



# Witness Panel Testing

After  
Construction

- Prepared by Installer
  - 3 panels minimum
  - 1 layer of CFRP
- Witnessed by Inspector
- Tested by the Independent Testing Agency (ASTM D3039)
- Evaluated by Engineer



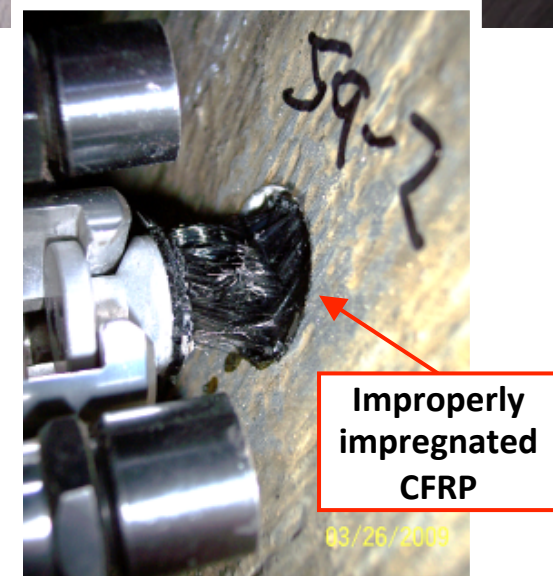
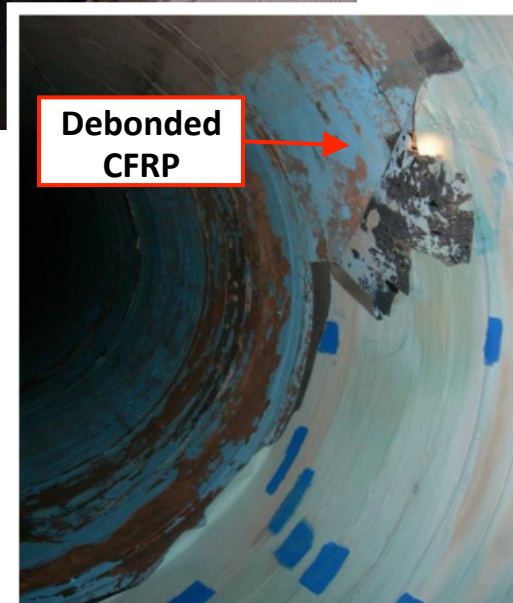
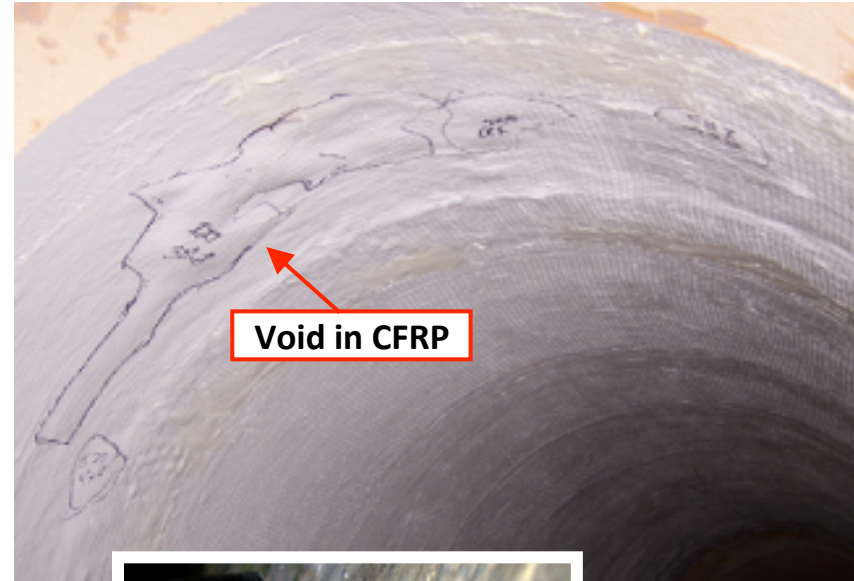
# Case Histories

## Over 40 successful projects in the last 3 years ...

- Constellation Energy Brandon Shores Power Plant
  - Lined (55) 102 in. PCCP under the switch yard (88,000 sq.ft application) in 22 days.
  - Lining of additional (51) 102 in. PCCP coming up.
- Miami-Dade Water and Sewer Authority
  - Ongoing CFRP repair program on more than (70) 48 in. to 96 in. PCCP.
  - Utility able to perform repairs by minimizing impact on community.
- APS Cholla Power Plant
  - Lined (20) 66 in. PCCP (22,000 sq.ft application) in 10 days.
  - Now planning additional CFRP repairs.



# Lack of QA (by Others)



# Conclusions

- Internal CFRP repair of pipes requires consideration of loads, limit states, and quality control procedures that are much different from those for other structures.
- Owners should be active participants in the repair process to ensure selection of qualified engineers, materials, installers, inspectors, and testing agencies.
- Manufacturers should be aware of the material qualification requirements, complete the missing data (e.g., creep, durability), and train Installers of their material.
- Contractors should be aware of all QA procedures for material preparation, installation, and curing.
- Lack of experience and quality control may lead to failure of CFRP liner.
- A design and installation standard is currently under development by AWWA.

# Questions ?

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