

Carbon Fiber as a Long Term Repair Solution

Based On the Reported Structural Properties of Tested CFRP samples
Submerged in Water for Eight Years and In-Situ Field Inspection



Authors

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Outline of the Presentation

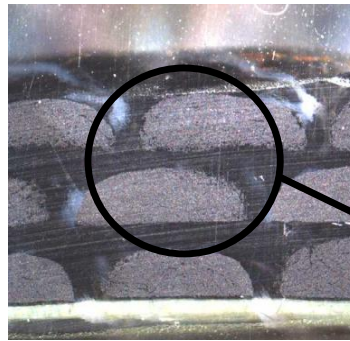
- Background on CFRP strengthening
- Motivation for Use of Carbon Fiber Structural Liners
- MWD' s 10-Year Carbon Fiber Lining Investigation Program
- Carbon Fiber Lining Pilot Project- Allen McCulloch Pipeline
- Structural Testing Results from 8-Year Durability Study
- Results from In-Situ Field Investigation
- Conclusions for a Durable CFRP System

Background of CFRP Strengthening

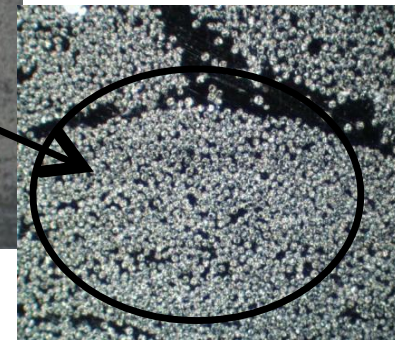
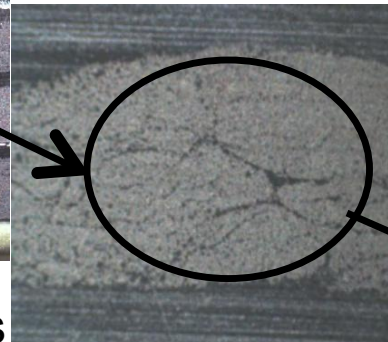
- Brought to civil infrastructure 25 years ago
- First for seismic retrofit, now many different applications
- Anisotropic nature -provides optimized usage of material



Retrofit of a Column



Close-up of fibers



CFRP: Carbon Fiber Reinforced Polymer

Motivation for Use of Carbon Fiber Liners

Avoid Pipeline Failure



Motivation for Use of Carbon Fiber Liners

Traditional Options for Pipeline Structural Repair



Post-tension repair



Dig up and repair (slipline)



Dig up and replace

Motivation for Use of Carbon Fiber Liners

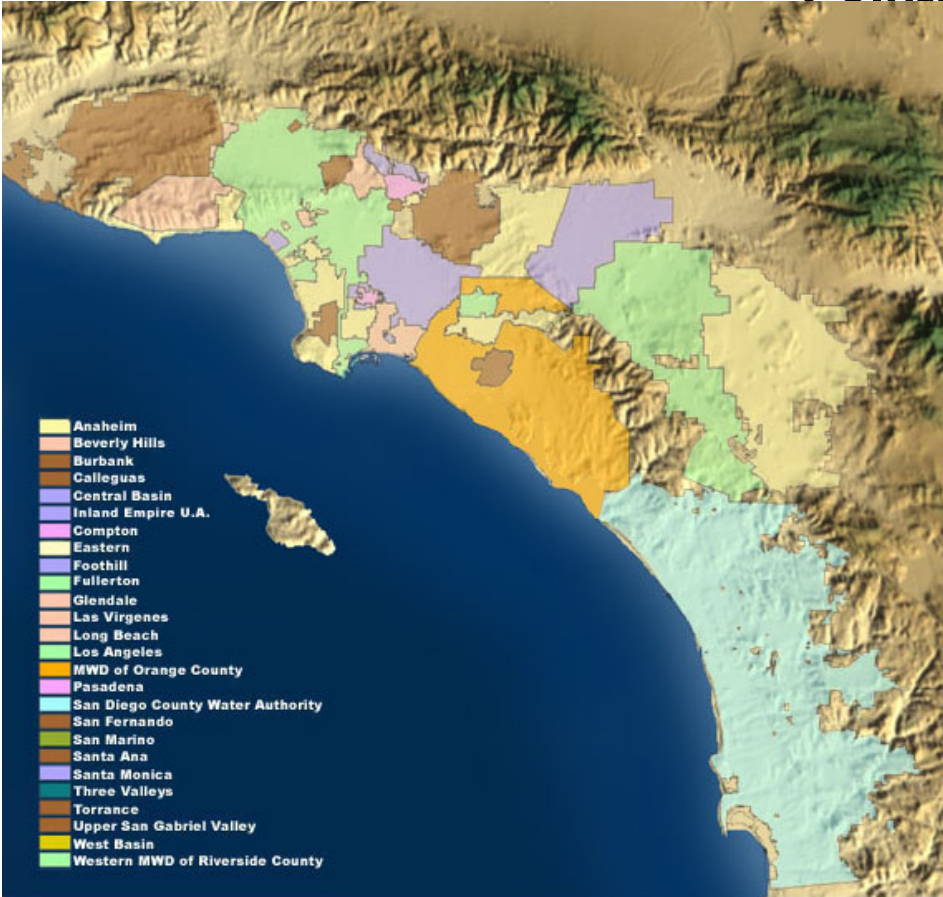
Features of Carbon Fiber

- Trenchless
- Rapid Installation
- Non-Corrosive
- Fully Structural
- Minimal Capacity Loss
- High Resistance to Abrasion
- High Resistance to Corrosion and Chemicals
- Potential for Long Service Life



Motivation for Use of Carbon Fiber Liners

MWD's Challenges Regarding Extended Shutdowns, Dig-up Solutions



MWD's
Member
Agencies



MWD Carbon Fiber Lining Investigation, 2000-Current

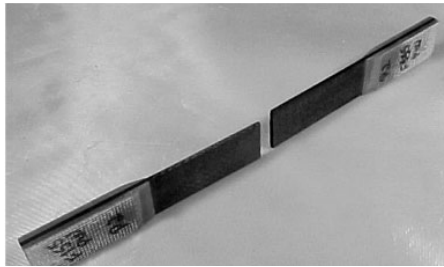
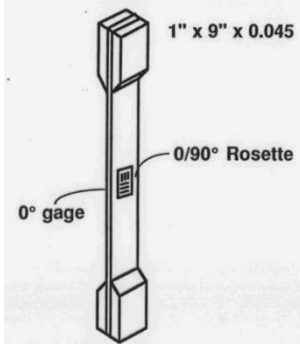
- Verify Mechanical Properties
- Evaluate Materials Performance (Durability)
- Evaluate Water Quality Concerns
- Evaluate Construction & Structural Concerns
- Develop Pilot Project Specifications/ Implement Project
- Monitor Long Term Performance of In-Service CFRP Liners

Mechanical Property Testing

Tests Performed by MWD

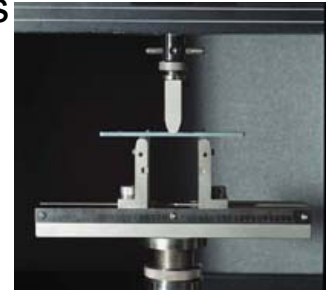
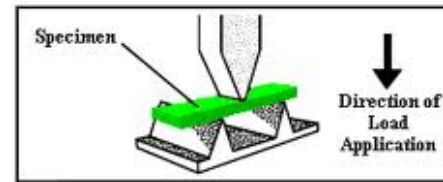
Tensile Testing

- ASTM D-3039, Tensile Properties of Polymer Matrix Composite Materials

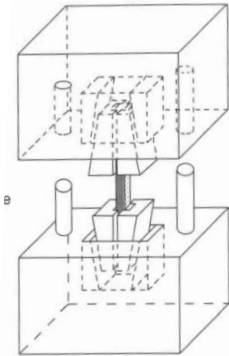


Flexural Testing

- ASTM D-790, Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials



Compression Testing



Adhesion Strength

- ASTM D-4541, Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers



Mechanical Property Testing

Tests Performed by MWD



Materials Performance Testing (Durability)

Tests Performed by MWD

- **Immersion**

- ASTM D-870, Practice for Testing Water Resistance of Coatings Using Water Immersion

- **High Humidity**

- ASTM D-2247, Practice for Testing Water Resistance of Coatings in 100% Relative Humidity

- **Cathodic Disbonding**

- ASTM G-8, Test Methods for Cathodic Disbonding of Pipeline Coatings

- **Wear**

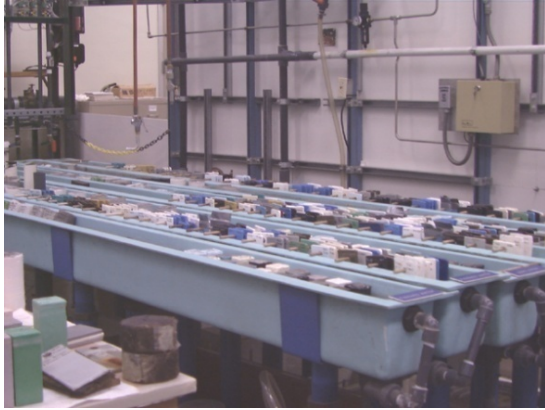
- ASTM D-4060, Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser

- **Atmospheric**

- ASTM G-7, Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials
- ASTM G-155, Practice for Operating Xenon Arc Light Apparatus for Exposure of Nonmetallic Materials

Materials Performance Testing (Durability)

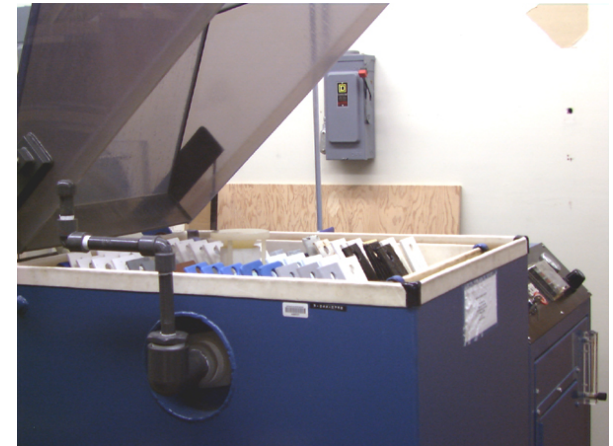
Tests Performed by MWD



Immersion Testing



Cathodic Disbonding

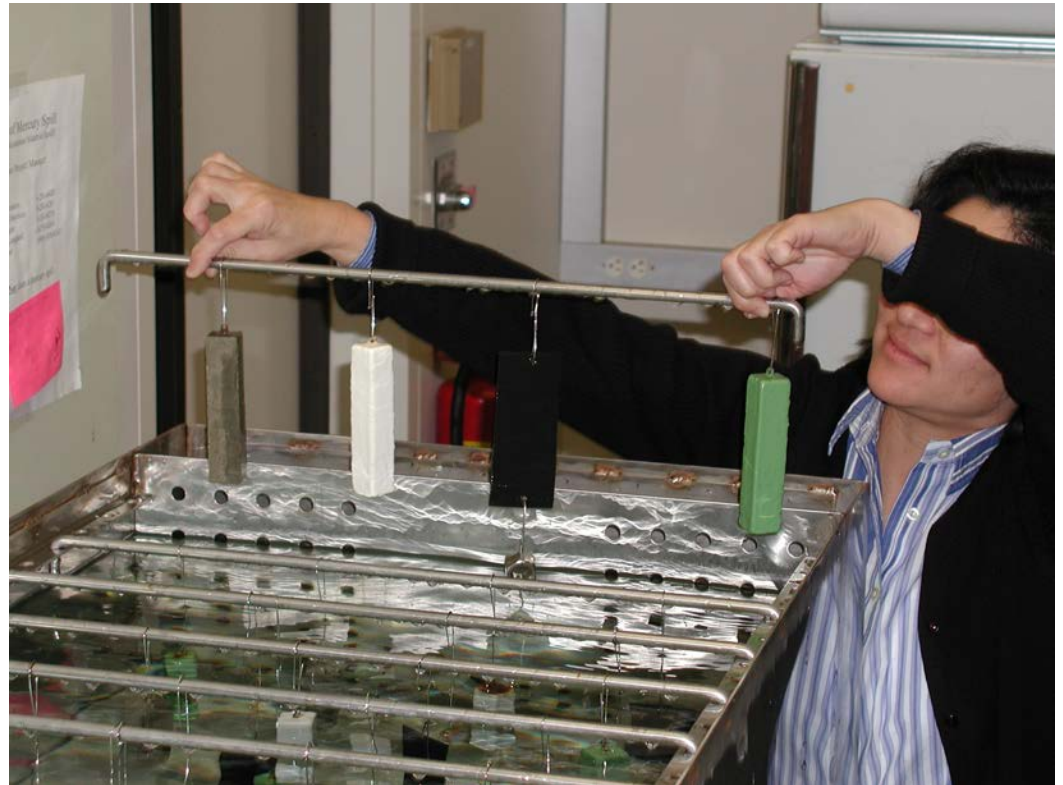
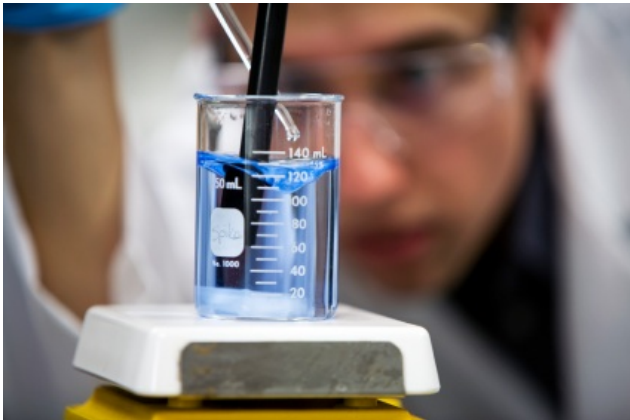


High Humidity

Water Quality Testing

Tests Performed by MWD

- **Leachables**
 - NSF 61
 - Taste & Odor
- **Biogrowth**
 - HPC



Additional Materials Performance Testing

AC125 Durability Requirements

- **Exterior Exposure**
 - Per ASTM G 153 in weatherometer chamber for minimum 2000 hours
 - Acceptance: Retain 90% physical properties
 - Surface changes affecting performance subject to examination
- **Freezing and Thawing**
 - Cycles for three weeks at 4 hrs at 0°F, 12 hrs in 100% RH at 100°F
 - Acceptance: Retain 90% physical properties
 - Surface changes affecting performance are unacceptable
- **Alkali Soil Resistance**
 - Per ASTM D 3083 for 1000 hours
 - Acceptance: Retain 90% physical properties
 - Surface changes affecting performance are unacceptable

Additional Materials Performance Testing

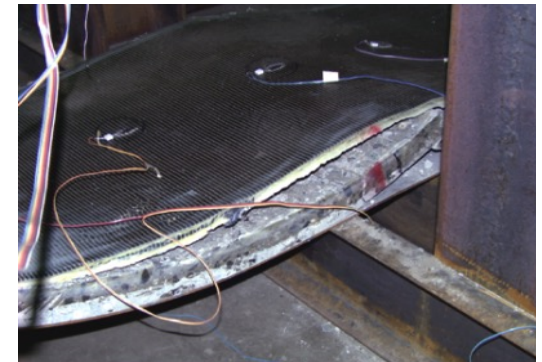
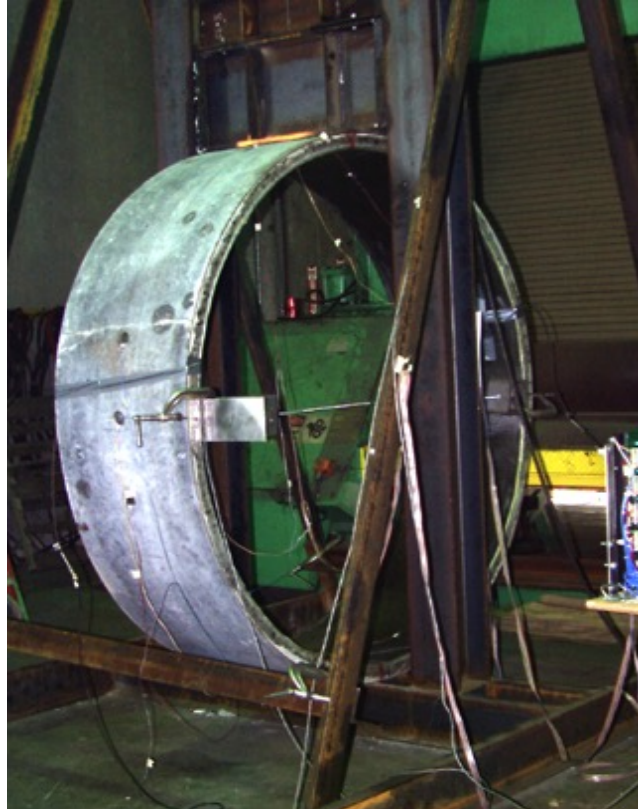
AC125 Durability Requirements

- Aging
 - 1000, 3000, and 10,000 hour exposure for:
 - Water Resistance
 - Saltwater Resistance
 - Alkali Resistance
 - Dry Heat Resistance
 - Acceptance: Retain 90% at 1000 hours, 85% at 3000 hours
 - Bond strength per ASTM D4541 or C297 also included
 - Surface changes affecting performance are unacceptable
- Drinking water exposure
 - Evaluated in accordance with NSF 61

Construction & Structural Testing

Tests Performed by MWD

- Full Scale Pipe Lining
- D-Load Testing



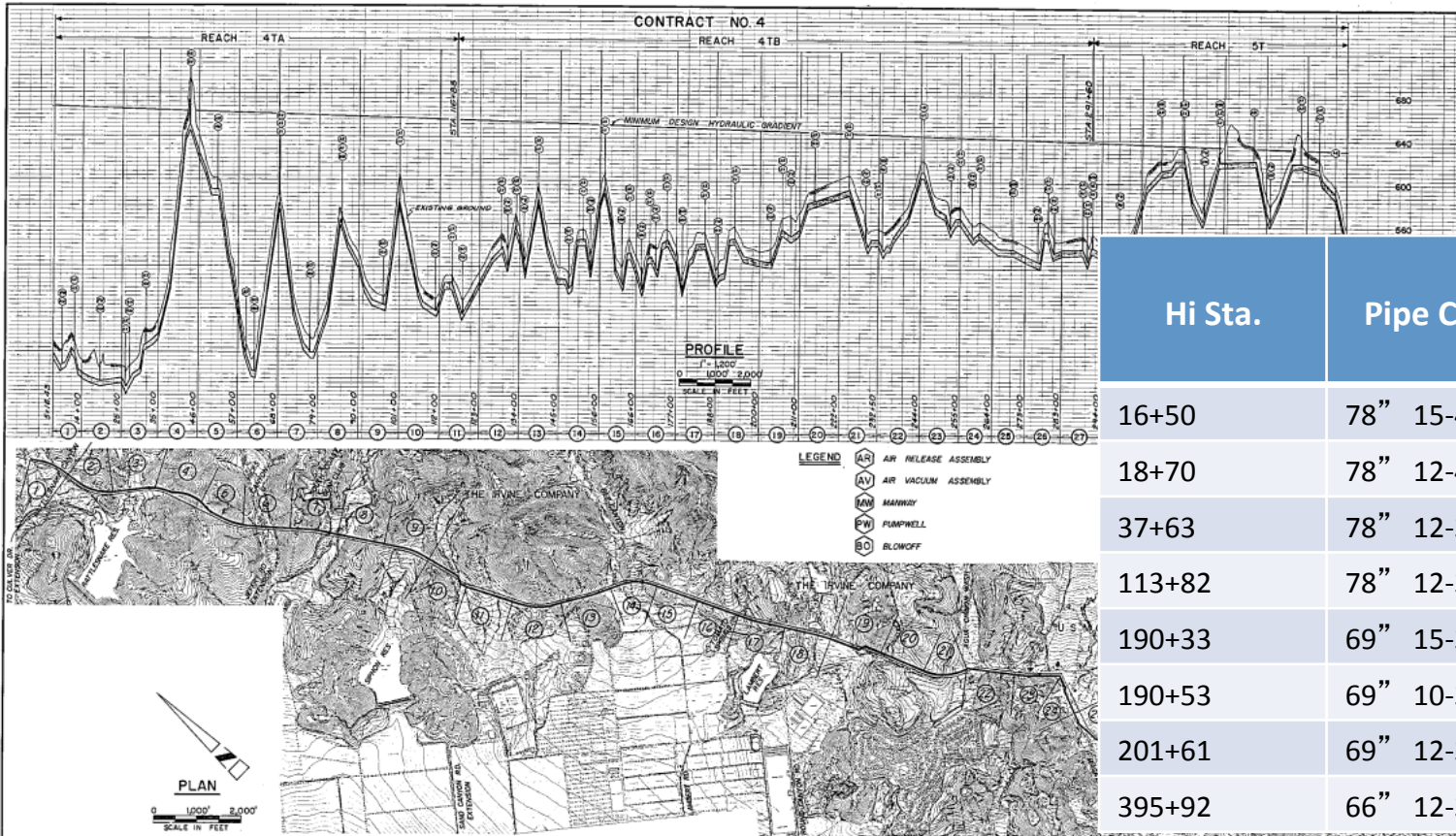
Pilot Project Specifications- Allen McColloch Pipeline (AMP)

Structural Design – Analytical Model*

- Design Based on Semi-Rigid Pipe Analysis
 - Internal Pressure – Barlow Equation for Composite Pipe Section
 - Strain Limited Design (0.0012)
- Marston Coefficients for Ground Loading
- Iowa Deflection Formula by Spangler
- Watkins/Roark for Pipe Stiffness

*Analysis proposed and developed by Rudy Loera, MS, PE

Pilot Project Specifications (AMP)



Hi Sta.	Pipe Class	No. of Hoop Layers of CFRP
16+50	78" 15-450	9
18+70	78" 12-450	9
37+63	78" 12-375	8
113+82	78" 12-375	7
190+33	69" 15-375	6
190+53	69" 10-350	6
201+61	69" 12-350	5
395+92	66" 12-375	5

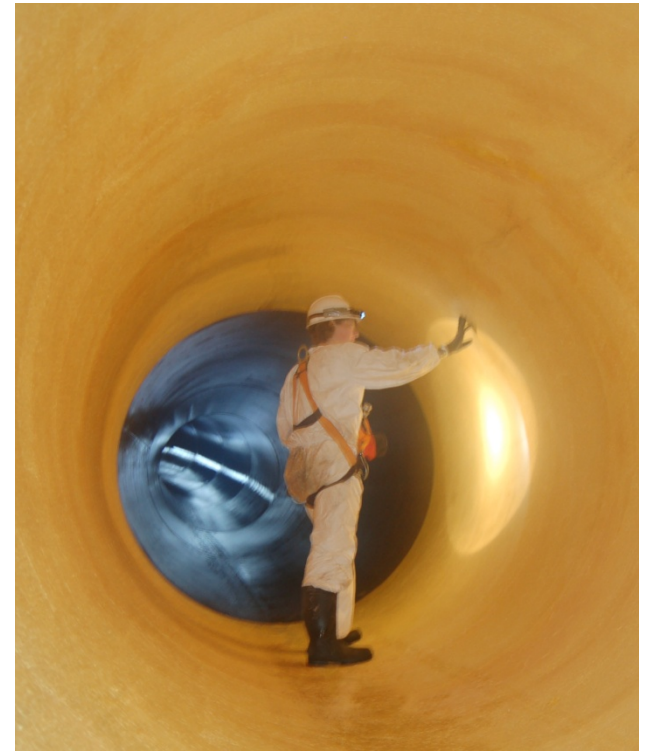
NO. DATE DWN CAD APPR REVISIONS	DESIGNED: S.V.H. DRAWN: S.V.H. CHECKED: S.V.H.	APPROVED: [Signature] DATE: [Date]	Boyle Engineering Corporation CONSULTING ENGINEERS 1501 OAK ST NEWPORT BEACH, CA 92663	CONTRACT NO. 4	DRAWING G-7
	SANTIAGO AQUEDUCT PARALLEL A PROJECT OF MUNICIPAL WATER DISTRICT OF ORANGE COUNTY WATER FACILITIES CORPORATION	CONDENSED PLAN AND PROFILE		SHEET 7 OF 170	

Construction Inspection for Quality

- Surface Preparation
- Layout Sequencing
- Installation
 - Mixing Materials
 - Pot Life
 - Saturation
 - Layup
- Quality Control

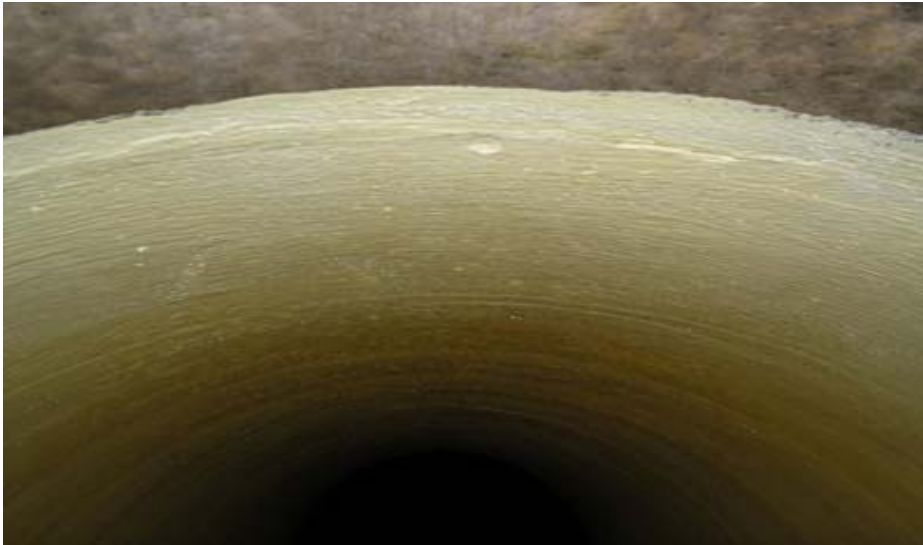


Inspection of Carbon Fiber Liner after 8 Years in Service



Visual Inspection of Carbon Fiber Liner, 8 Years in Service

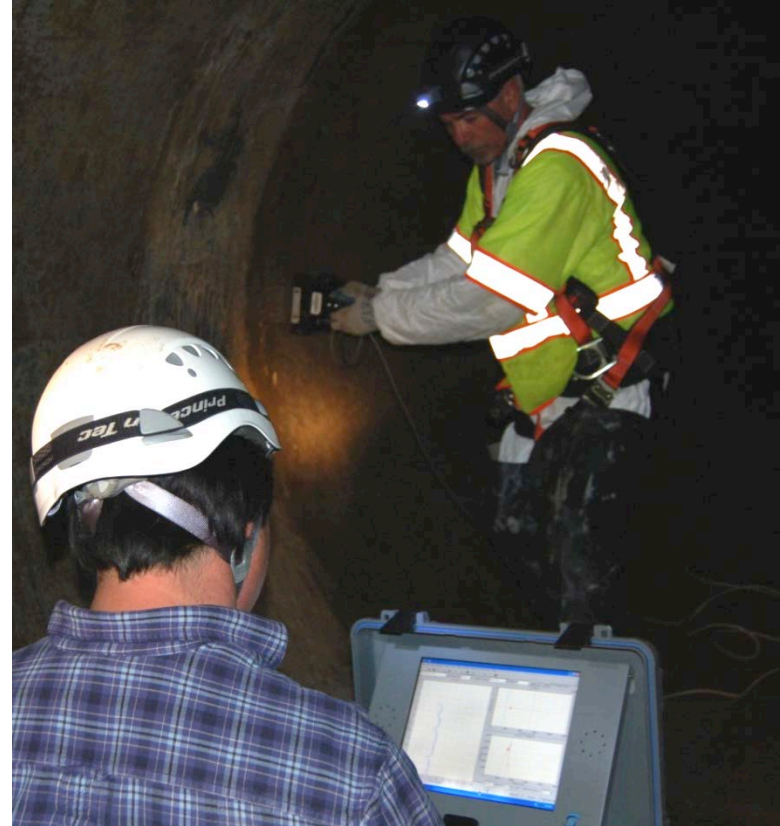
- No blisters or delaminations.
- No cracking or checking, softening, or edge lifting



Additional Inspection Techniques Employed



RFRC Technology



Impact-Echo Testing

Results from Testing of 8-Year Water Immersed Samples

All Values remain comparable, above the data sheet values



Properties	Un-aged Samples	8-year Water Immersed Samples	Published Datasheet Values
	Average ± STD	Average ± STD	Typical Test Value
Tensile Strength (ksi)	128.7±15.6	139.5 ± 18.5	127.0
Tensile Modulus (10 ⁶ psi)	12.7±0.14	10.6 ± 1.23	10.5
Breakage Strain (%)	1.16±0.17	1.3 ± 0.1	1.2

Outcome: CFRP System Exhibits Strong Performance over 8-Year Test

Conclusions for Durable Carbon Fiber Liner System

Durability of the CFRP system is achievable given:

- Quality Materials
- Conservative Design
- Quality Construction



Thank you!

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