structural TECHNOLOGIES

30 to 96-inch Pipelines Upgrade Case Study: Navigating Safety Related Pipeline Upgrades with CFRP

Agenda

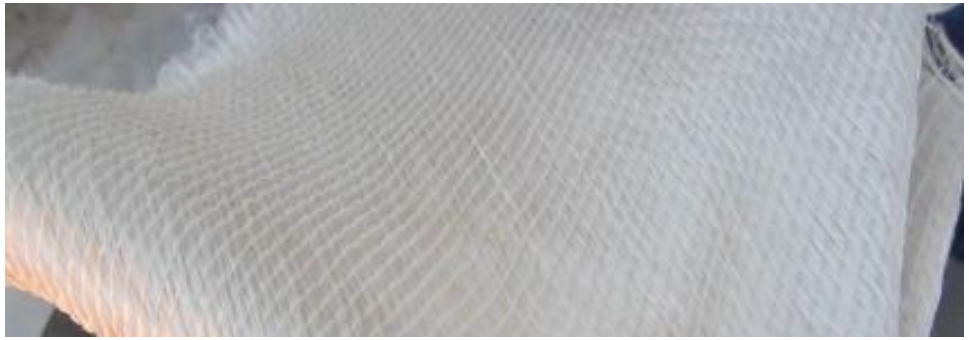
- Overview of Carbon Fiber-Reinforced Polymer (CFRP)
  - Technical overview
  - Design process
  - Installation process including safety, quality control
- Relief/Alternative Request Process
- Managing Safety-Related Processes
- Safety-Related CFRP Installation

Carbon Fiber Technical Overview

CFRP = Carbon Fiber Reinforced Polymer

GFRP = Glass Fiber Reinforced Polymer

- Carbon Fiber provides structural strength
- Glass fiber provides water-tightness and dielectric barrier
- Epoxy resin provides durability



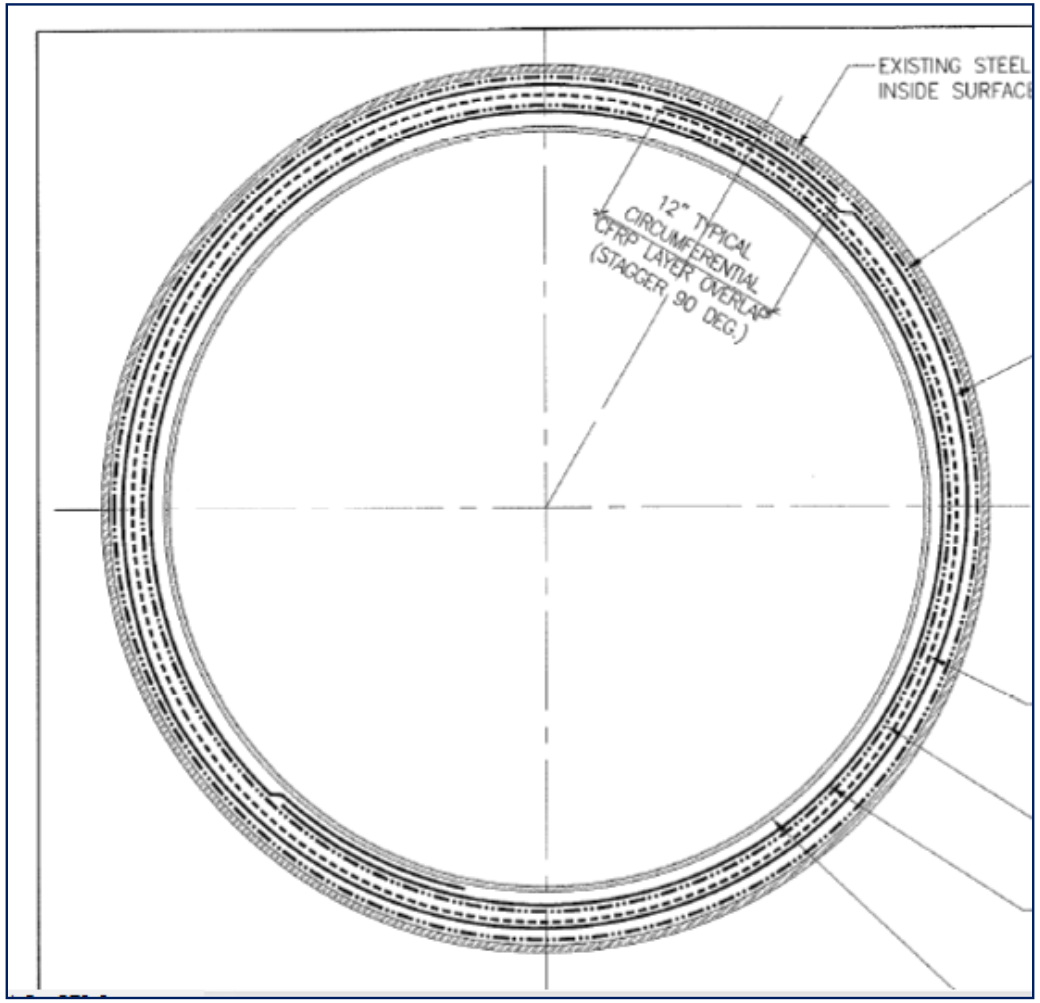
Carbon Fiber Technical Overview

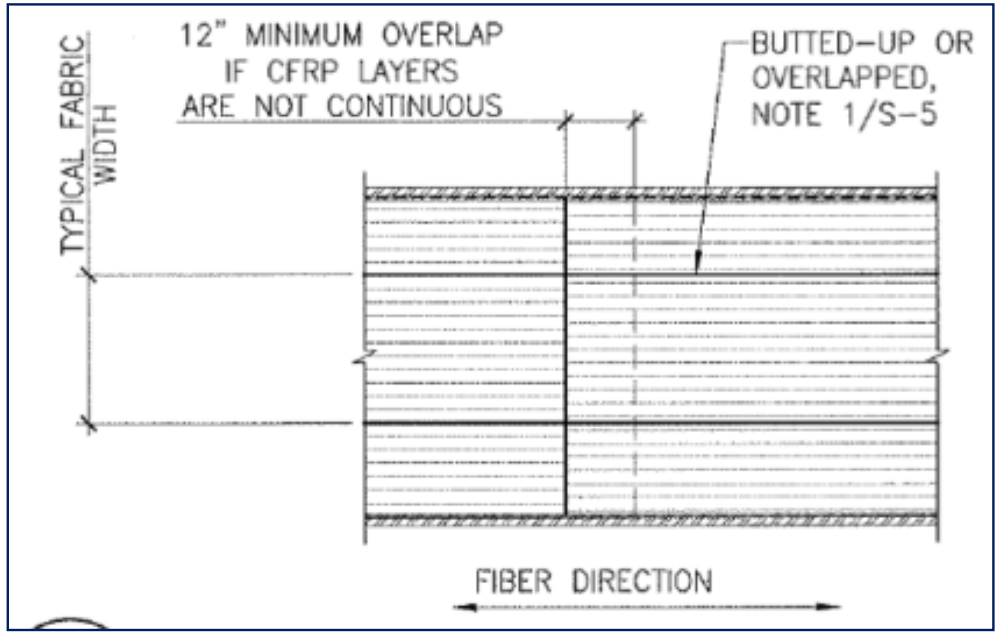
History of Carbon Fiber Reinforced Polymer (CFRP)

- 1950s: CFRP for aerospace applications
- 1980s: CFRP is used to repair civil infrastructure
- 1990s – early 2000s: Various utilities start using CFRP to internally repair large diameter pipe
- Mid-2000s: CFRP repair of pipe is widespread
- 2009: AWWA Concrete Pressure Pipe Committee appoints a subcommittee
- 2011: Water Research Foundation awards the first research project to form the technical basis of the standard
- 2012: ASME Task Group formed for Code Case Repair of Class 2 and 3 Piping by Carbon Fiber Reinforced Polymer Composite, ASME Section XI, Division 1
- 2013 – 2015: Additional research on watertightness, degree of cure, etc.
- 2015: AWWA C305 Standard for CFRP Renewal and Strengthening of PCCP is complete (published 2018)
- 2017: NRC approves use of the V-Wrap CFRP system for safety related piping at a nuclear plant
- 2018: Safety related CFRP implemented at nuclear plants
- 2019: NEA Top Innovative Practice (TIP) award, “Best of Best” awarded to safety related CFRP project team

Carbon Fiber Design Process

Sample Drawing Package
Schematic cross section of pipe and overlaps



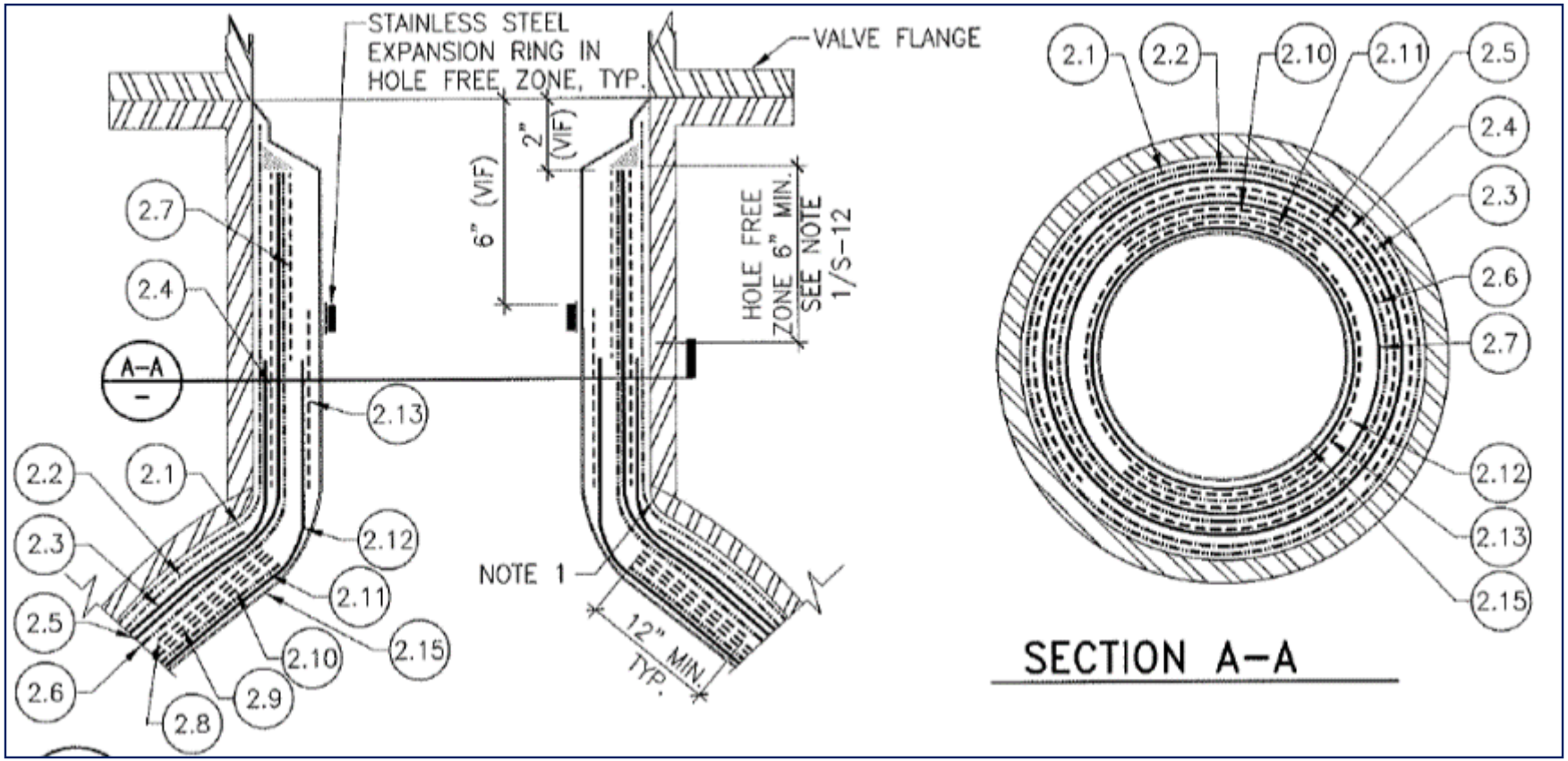


(Not to Scale)

Carbon Fiber Design Process

Sample Drawing Package

Schematic detailing for different pipe configurations



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Installation Process

Installation Process: Laydown Area & Setup

Installation Process: Laydown Area & Setup

Installation Process: Mixing and Saturation

Project Steps:

- Materials arrive on site in premeasured containers for part A and B components
- Designated mixing region is an isolated area to avoid material contamination
- Mechanical saturator ensures consistent application of epoxy to carbon fiber

QC Documentation:

- Lot numbers of fabrics and epoxies are documented
- Gap between saturator rollers measured and calibrated using weigh test
- Weigh test verifies ratio of fabric to epoxy is within tolerance

Installation Process: Surface Preparation

Project Steps:

- Surface preparation using abrasive blasting (CSP-3 for concrete, SSPC-10 for metallic surfaces
- Steel plates welded as needed
- Chloride level reduced using Chlor-rid rinse
- Surface preparation is verified by performing an adhesion test per ASTM D4541 on the prepared pipe

QC Documentation:

- Minimum surface roughness documented
- Failure mode documented
- Minimum pull-off test of 300 psi required away from terminal ends and 700 psi required at terminal ends

Installation Process: Carbon Fiber Application

Project Steps:

- Unidirectional mechanically saturated carbon fiber fabric installed in both longitudinal and circumferential directions
- CFRP design serves as stand alone system to resist all loads without reliance on host pipe

QC Documentation:

- Air temperature, surface temperature, and humidity during installation documented
- Alignment of CFRP layers observed (maximum of 5 degree misalignment)
- Minimum development length of 12in in fiber direction

Installation Process: Carbon Fiber Final Cure

Project Steps:

- After top coat is installed, final cure of CFRP system is performed at elevated temperature

QC Documentation:

- Air temperature, surface temperature, and humidity during CFRP cure recorded
- Degree of cure testing performed to verify degree of cure achieved for CFRP system

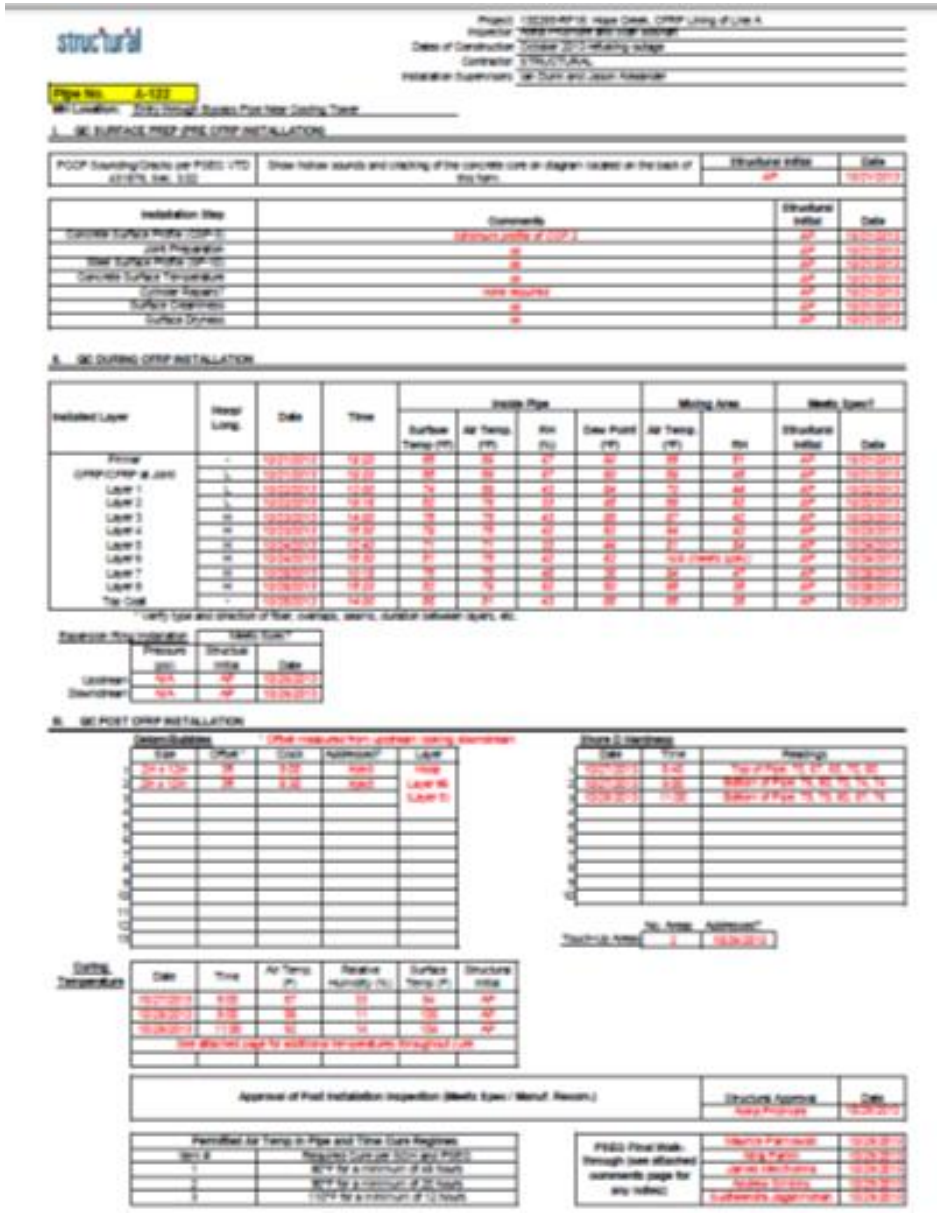
Quality Control: Documentation

Comprehensive documentation for each stage of implementation:

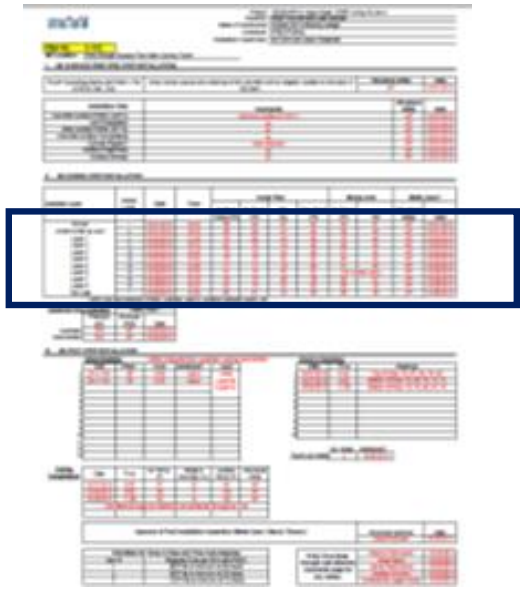
- Material verification
- Surface preparation
- Mixing and saturation
- CFRP liner installation
- End details and special detailing
- Top coat
- Final cure

Purpose - aligning multiple QA/QC parties:

- 3rd Party inspector
- Full time quality assurance manager
- Multiple owner representatives



Quality Control: Documentation



Multiple data points recorded through every step of project

Installed Layer	Hoop/ Long.	Date	Time	Inside Pipe				Mixing Area		Meets Spec?	
				Surface Temp (°F)	Air Temp. (°F)	RH (%)	Dew Point (°F)	Air Temp. (°F)	RH	Structural Initial	Date
Primer	-	10/21/2013	19:20	68	66	67	60	66	61	AP	10/21/2013
GFRP/CFRP at Joint	L	10/21/2013	19:20	68	66	67	60	69	46	AP	10/21/2013
Layer 1	L	10/22/2013	12:00	74	69	43	54	70	44	AP	10/22/2013
Layer 2	L	10/22/2013	16:16	62	76	33	46	66	62	AP	10/22/2013
Layer 3	H	10/23/2013	14:00	78	76	43	66	67	42	AP	10/23/2013
Layer 4	H	10/23/2013	16:30	79	76	42	62	64	42	AP	10/23/2013
Layer 5	H	10/24/2013	12:40	71	71	33	44	61	64	AP	10/24/2013
Layer 6	H	10/24/2013	16:30	61	76	42	62	N/A (meets spec)		AP	10/24/2013

Quality Control: Insitu and Post-Installation Testing

- UT readings at terminations
- Chloride test
- Weight ratio test
- Adhesion test (ASTM D4541)
- Tensile test (ASTM D3039)
- Material cure testing

Quality Control: Tensile Test Panels

Project Steps:

- During each shift of CFRP installation, two test panels are fabricated

QC Documentation:

- Air temperature and humidity during CFRP test panel fabrication are recorded
- Lot numbers for carbon fiber fabric documented
- Once panels cure, they are sent off to 3rd party test facility for tensile tests per ASTM D3039

Alternative/Relief Request Process

Reason for use of CFRP

Eliminate high maintenance weld repairs and re-coating cycles

Alternative/Relief Request Process

Technical Components *(italics = written by Structural Technologies)*

- ASME Code Components Affected (*Enclosure 2- scope, schedule, definition of terms*)
- Material inspection and controls (*Enclosure 3- materials inspections, controls and qualification testing*)
- Design basis (Enclosure 4- drawings), (Enclosure 5- calculations) (Enclosure 6- design specification)
- Installation (*Enclosure 7- sample project installation procedures*)
- Examination and Testing (*Enclosure 8- sample project quality plan and QA/QC forms*)
- Qualifications and Training (*Enclosure 9- sample qualification and training package*)
- Operational Experience (*Enclosure 10- successful and failed applications*)
- In-service Inspection (Enclosure 11- sample in-service inspection)

Alternative/Relief Request Process

Overview

- After documents were developed for submission, one (1) year for review and approval by NRC
- Collaborative effort of project team which included Owner, Material Manufacturer, Designer, and Installer
- Vertical integration of manufacturer and installer was critical
- Seamless relationship with designer was key factor (15 years history)
- Approval was gained from NRC on a project, material and team-specific basis

Alternative/Relief Request Process

Success factors

- Owner with an understanding of big picture – long term repair with 50-year design service life allows for shift in focus to other critical plant components
- Manufacturer/installation company - Structural Technologies - with Nuclear Culture and NQA-1 in place
- Technical and operational expertise within Structural Technologies as the leading provider of carbon fiber for pipeline upgrades in the US
- Designer with 20+ year track record designing carbon fiber systems for pipeline upgrade projects

Managing Safety-Related Processes

Materials Manufacturing, Inspection & Controls

- Epoxy components and carbon fiber material are manufactured as QA Category 1 in accordance with 10CRF 50 Appendix B and ASME NQA-1.
- The materials are controlled using a comprehensive process that includes;
  - Technical performance criteria.
  - Qualification testing at the component and end state levels.
  - Testing methods that assure components are verifiable and traceable from the manufacturer to installation.
  - Quality Control and Quality Assurance methods and records that verify manufacturing, storage and installation of epoxy and carbon fiber components as specified by the Design Authority.
  - Materials are delivered in factory sealed and labeled containers that bear the manufacturers name, product identification, component designation, lot number, date of manufacture, and shelf life.

Managing Safety-Related Processes

Installation

- Because of Structural Technologies' established, comprehensive procedures, the shift to safety-related piping included only the addition of a few quality control steps.

- Adjustments for safety-related projects included:
  - Closer coordination and responsibility allocations for each QA/QC check
  - Temperature monitoring during all phases of manufacturing and installation
  - In-process cure testing at laboratory
  - Expedited tensile testing to confirm results

NOTE: Parties marked with an "O" are REQUIRED to **observe** the test or inspection.
Parties marked with a "P" will **perform** the test or inspection.

Action	Structural	Dom. Rep	3rd Party QC/QA	CFRP Designer
Marking of scope locations to be CFRP lined	O	P	-	-
Marking of localized repair locations (water ingress)	O	P	-	O*
Chloride Test				
Initial Chloride Test – NOTE: requires NACE Coating Inspector Level 1 (CIP) qualification to perform	P	O	O	O
Pull-off Tests on Mock-Up Areas				
Surface Prep Verification prior to mock-up install.	P	O	O	O
Pull Test - Prelim. Existing Coating (pucks to coating)	P	O	O	O
Pull Test of Mock-ups	P	O	O	O
V-Wrap Installation				
Surface profile verification throughout pipe	P	O	O	O
Surface profile verification at terminations	P	O	O	O
Surface Dryness/Cleanliness	P	O	O	O
Witness Panels Preparation	P	-	O*	O*
Weight Ratio Test	P	-	O	O*
Material Lot Numbers	P	-	O*	-
Individual Layer Installation	P	O*	O*	O*
Inspect for Defects Requiring Corrective Action	P	P	P*/O	P
Verify Defects are Remediated	P	O*	O	O
DSC Testing of epoxy to determine degree of cure	-	-	-	P
End Terminations				
Expansion Ring Installation	P	O*	O	O
Final Walk Through	P	O	O	O

* Random sampling only

Project Example: Safety-Related 96-inch Metallic Piping

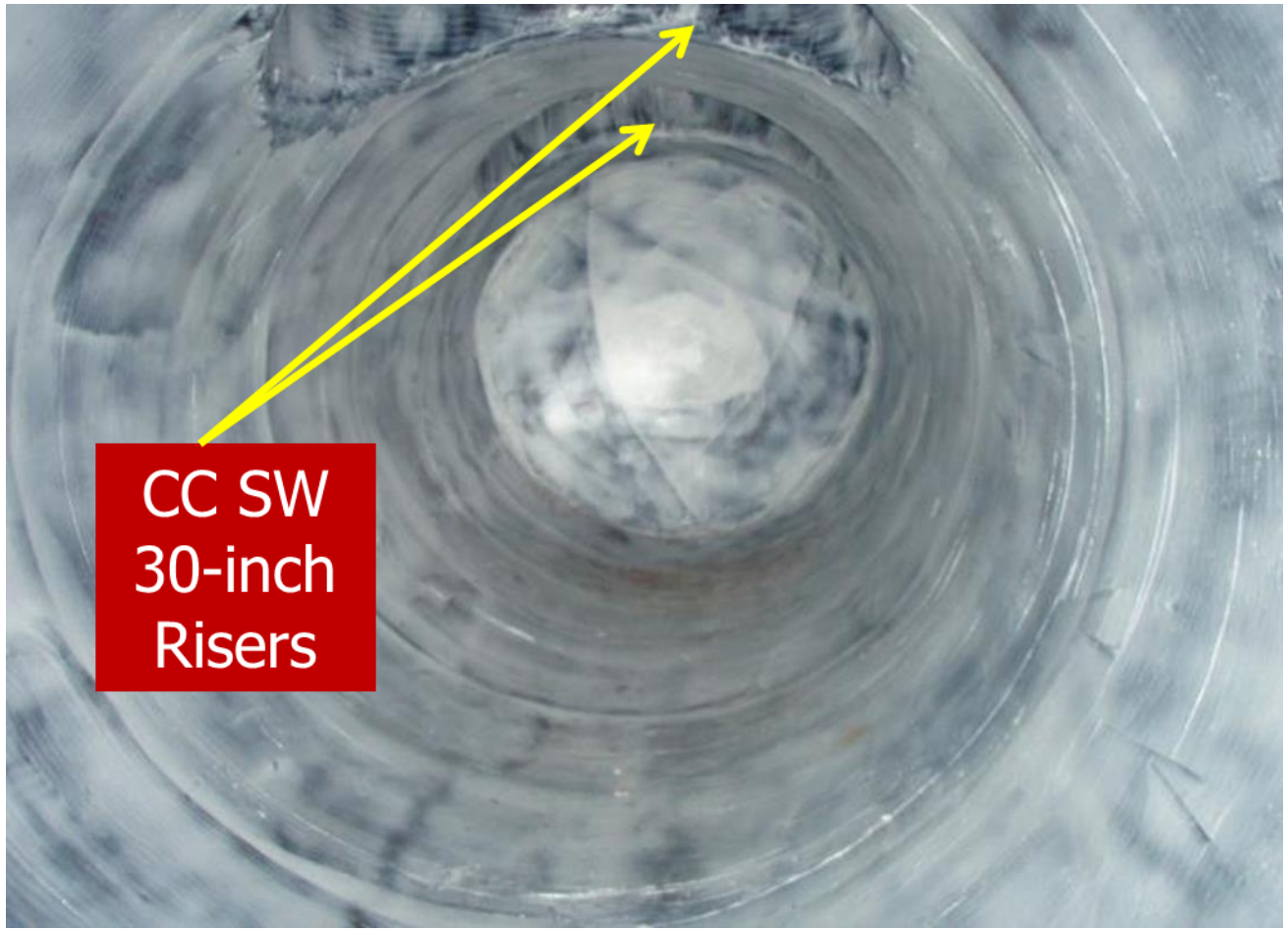
Project Example: Safety-Related Scope

- Two (2) projects completed to date under current NRC approval
- Scope of work on safety-related piping has included:
  - Spring 2018 – 260 lineal feet of 96-inch, 42-inch & 30-inch metallic piping
  - Fall 2018 – 330 lineal feet of 96-inch, 42-inch & 30-inch metallic piping
  - Fall 2019 – 330 lineal feet of 96-inch, 42-inch & 30-inch metallic piping
  - Multiple additional scopes already moving forward between Spring 2020 and 2025

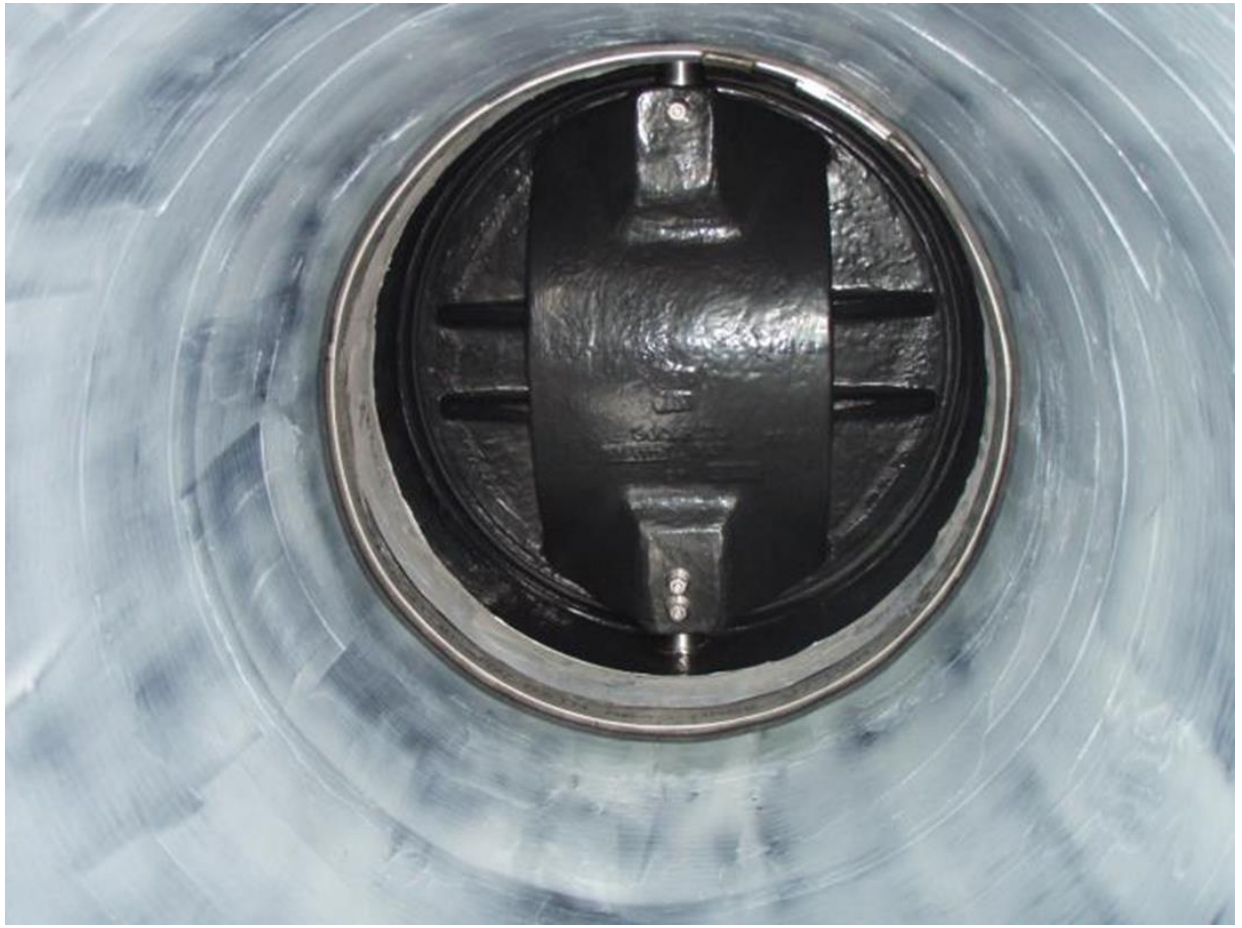
NOTE: Non-safety-related piping upgrades occurring simultaneously on multiple projects with similar size metallic piping within same station dating back to 2015

Project Example: Safety-Related 42-inch Metallic Piping

Project Example: Safety-Related 42-inch Piping



Project Example: 30-inch Safety-Related Piping Riser



Questions?

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