structural TECHNOLOGIES

A Structural Group Company

Silicon Valley Mid-Summer Emergency: Santa Clara Addresses Peak-Demand Repair of 96-inch Pipeline

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BACKGROUND

Santa Clara Valley Water District:

- Primary Water Source for Santa Clara Valley
- Flood management and wholesale water for:
  - 2 million people
  - 17 municipalities
- 121 billion gallons annually
- Pipeline inventory:
  - 142 miles of pipelines
  - Pipeline diameters 30 - 120 inches

Santa Clara Conduit:

- 96-inch prestressed concrete cylinder pipeline
- 23 miles long
- Critical pipeline conveying Central Valley Project water to Santa Clara County

PIPE RUPTURE

Site of ruptured pipe

- ~6:30 AM August 1, 2015
- Drastic pressure loss along Santa Clara Conduit
- Investigation determined location
- Rupture occurred during a power outage
- **20 million gallons** of water lost due to rupture

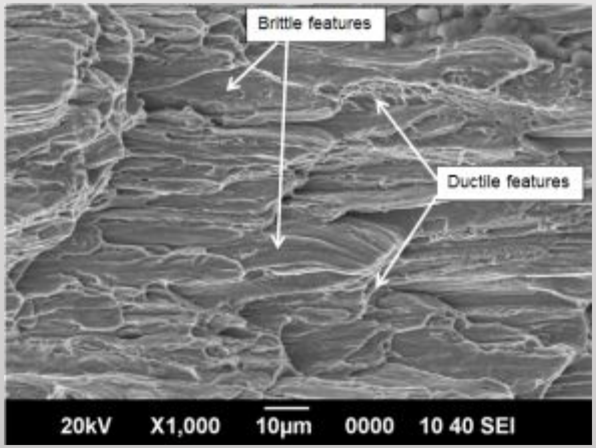
PIPE RUPTURE LOCATION & AREA IMPACTED

PIPE RUPTURE LOCATION & AREA IMPACTED

FORENSIC INVESTIGATION

- Scope of investigation
  - Forensic inspection on 6 August 2015
  - Metallurgical analysis of pretressing wire
    - Surface chemical analysis
    - Fractographic analysis to identify causes of fracture
    - Metallographic analysis to evaluate corrosion mechanism
  - Tension and torsion testing of prestressing wire
  - Petrographic analysis of mortar coating and concrete core
    - Evaluate quality of mortar and concrete
    - Identify evidence of deterioration
  - Testing absorption, density, permeability, and chloride content of mortar coating

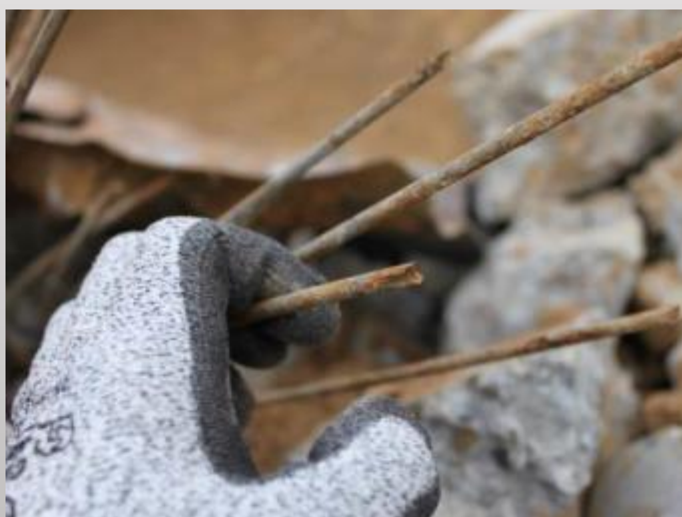
Torsion fracture surface of uncorroded wire



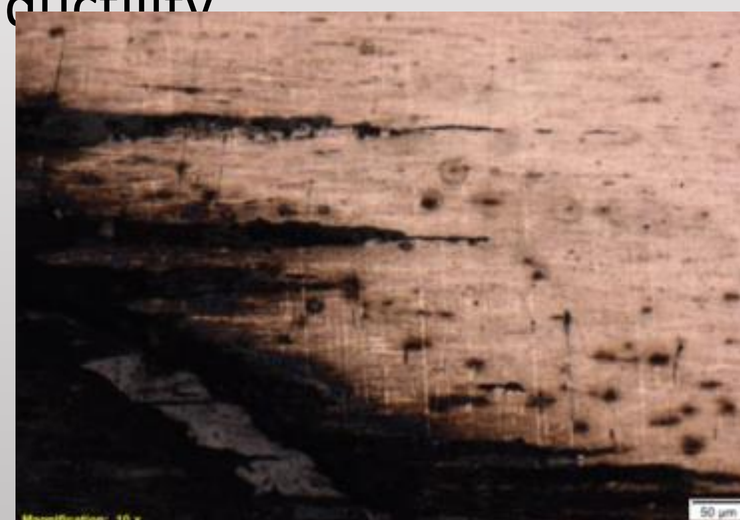
SEM micrograph of stepped fracture surface with mixed-mode (ductile and brittle) fracture

FORENSIC INVESTIGATION

- Prestressing wire
  - All wires broken between 1 and 12 ft from the downstream joint
  - Corroded wires with brittle fracture surfaces
  - Only a few wires in the failure zone had necking indications of ductile failure.
  - Mechanical tests show prestressing wire unaffected by corrosion has good strength and ductility



Brittle wire fracture surface

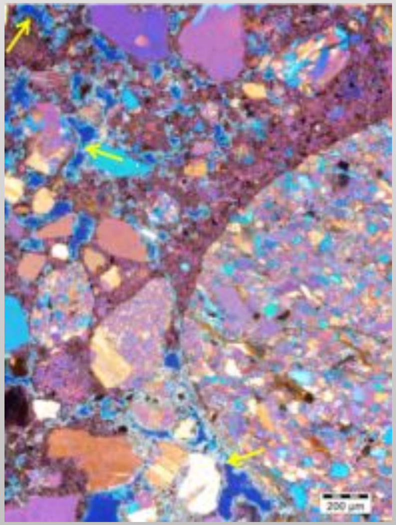


Longitudinal splits and corrosion oriented along the wire axis

FORENSIC INVESTIGATION

- Mortar coating
  - Corrosion staining on fractures through the thickness
  - Two distinct layers
    - inner layer lightly colored (higher w/cm ratio and/or higher void content)
  - Petrographic analysis identified high air void content and interconnected air voids in the mortar coating specimens
  - Chloride ion content low on outside and higher on inside surface

Layered mortar coating near downstream joint. Outer layer applied as a local patch.

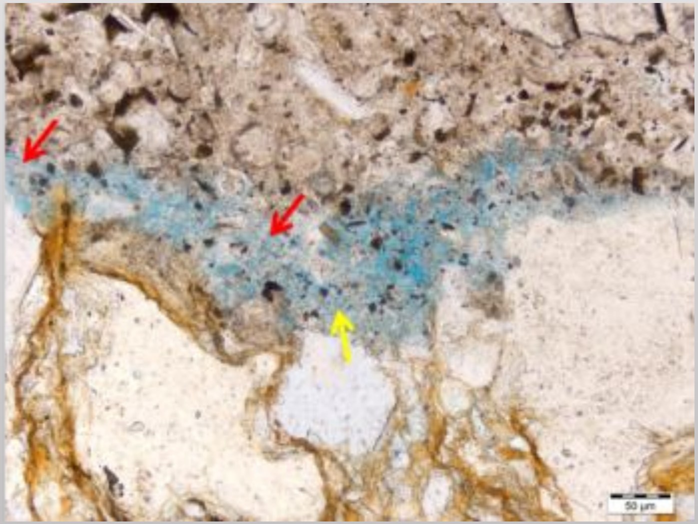


Ultrathin section of mortar with interconnected entrapped air voids (yellow arrows).

FORENSIC INVESTIGATION

- Concrete core
  - Fracture surfaces did not show fracture through the aggregates, an indication of weak concrete.
  - Concrete core from the failure area washed away during the rupture and removed during initial pipe demolition prior to inspection.
  - Petrographic analysis identified weak bond between the aggregate and cement paste, likely due to excess bleed water (wet aggregate).

Aggregate pullout in concrete core



Ultrathin section of concrete core showing bleed water along a coarse aggregate particle

FORENSIC INVESTIGATION

- Primary cause of failure was manufacturing defects
  - Highly porous mortar coating
  - Weak concrete in its core
  - Use of gauge 18 steel cylinder instead of the specified 16 gauge
- Failure mechanism
  - Porous mortar coating allowed ingress of moisture and air, resulting in carbonation of the cement paste and corrosion of the prestressing wires.
  - Corrosion resulted in hydrogen assisted brittle cracking of the wires.
- Timing of Failure
  - Transition from operating conditions to static head conditions after the power outage at Pacheco Pumping Station and subsequent valve closures.

CONDITION ASSESSMENT

Electromagnetic (EM) inspection

- Performed prior to visual and sounding inspection
- Marked wall of pipe potentially containing distress based on field interpretation of the electromagnetic inspection results

Internal visual and sounding inspection near ruptured pipe

- Valve Vault #4 (Sta. 11+26) to the bottom of the sloped section of pipeline near Sta. 13+00
- Detailed inspection of pipes marked based on EM inspection results
- no hollow sounding areas, no longitudinal cracks, no wide circumferential cracks, and no joint openings

THE RESPONSE

Factors:

- Timing critical – hot summer; peak demand
- SCVWD had spare pipe to replace ruptured segment
- Replacement of two adjacent distressed pipes not feasible within time available

Actions:

- Carbon Fiber-Reinforced Polymer (CFRP) liner as alternative to replacement of distressed segments
- Multiple specialty CFRP companies contacted – Work awarded based on experience and responsiveness
- Mobilization immediately after access available
- Repairs began within 7 days
- CFRP repairs completed in 8 days, including cure

Ruptured pipe visible after water subsided

CARBON FIBER REINFORCED POLYMER (CFRP) LINER REPAIR DESIGN

CFRP is a stand alone system

- Host pipe provides a form for CFRP repair
- Repair does not depend on host pipe for strength

CFRP based on LFRD approach

- Load factors
- Strength reduction factors
- Material adjustment factors
- Time effect factors – Short & Long term loads based on AWWA Draft Standards

CARBON FIBER REINFORCED POLYMER (CFRP) LINER REPAIR DESIGN

CFRP strengthening design loads include:

- Working pressure: 152 psi (350 ft of pressure head)
- Working plus transient pressure: 213 psi (1.4 x working pressure)
- 10 feet of soil cover
- Full vacuum inside the pipeline (-14.7 psi internal pressure)
- Internal temp variation of +/- 30^{o}F.

CARBON FIBER REINFORCED POLYMER (CFRP) LINER REPAIR DESIGN

Strength limit state designs considered:

- Circumferential rupture of CFRP laminate
- Circumferential buckling of CFRP laminate
- Longitudinal rupture of CFRP laminate
- Longitudinal buckling of CFRP laminate
- Longitudinal failure of CFRP
- Pipe end shear failure of CFRP

CFRP LINER INSTALLATION

Installation of a CFRP lining system involves application of sheets of carbon fiber fabric, saturated with a two part 100% solids epoxy, applied to the inside walls of the host pipe. Once secured they create a stand alone structural system.

Installation of CFRP liners consists of:

- Surface preparation
- Materials saturation
- Application of the materials
- Curing of the system

CFRP TERMINATION DETAIL

Inner core concrete chipped out and exposed steel prepared to near white metal in joint region

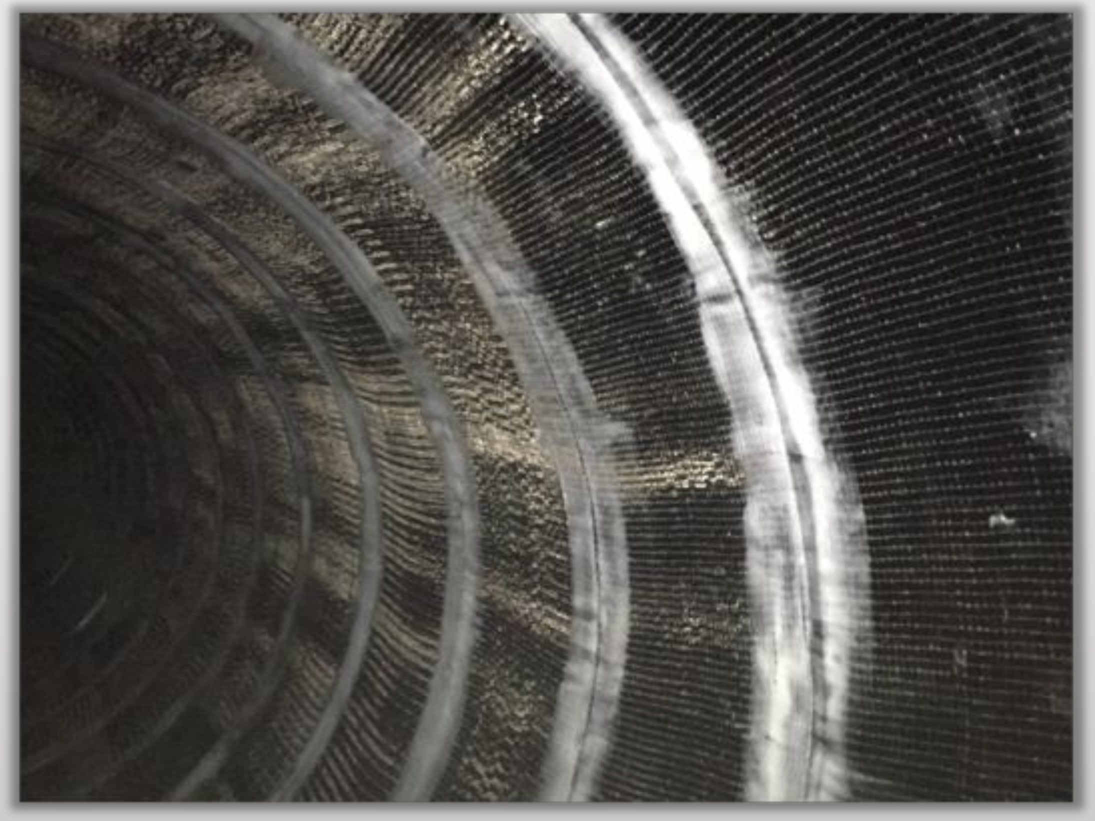
CFRP LINER INSTALLATION

Mechanical saturator for CFRP

CFRP LINER INSTALLATION

Installation of longitudinal layer of CFRP

CFRP LINER INSTALLATION



Installation of circumferential layer of CFRP

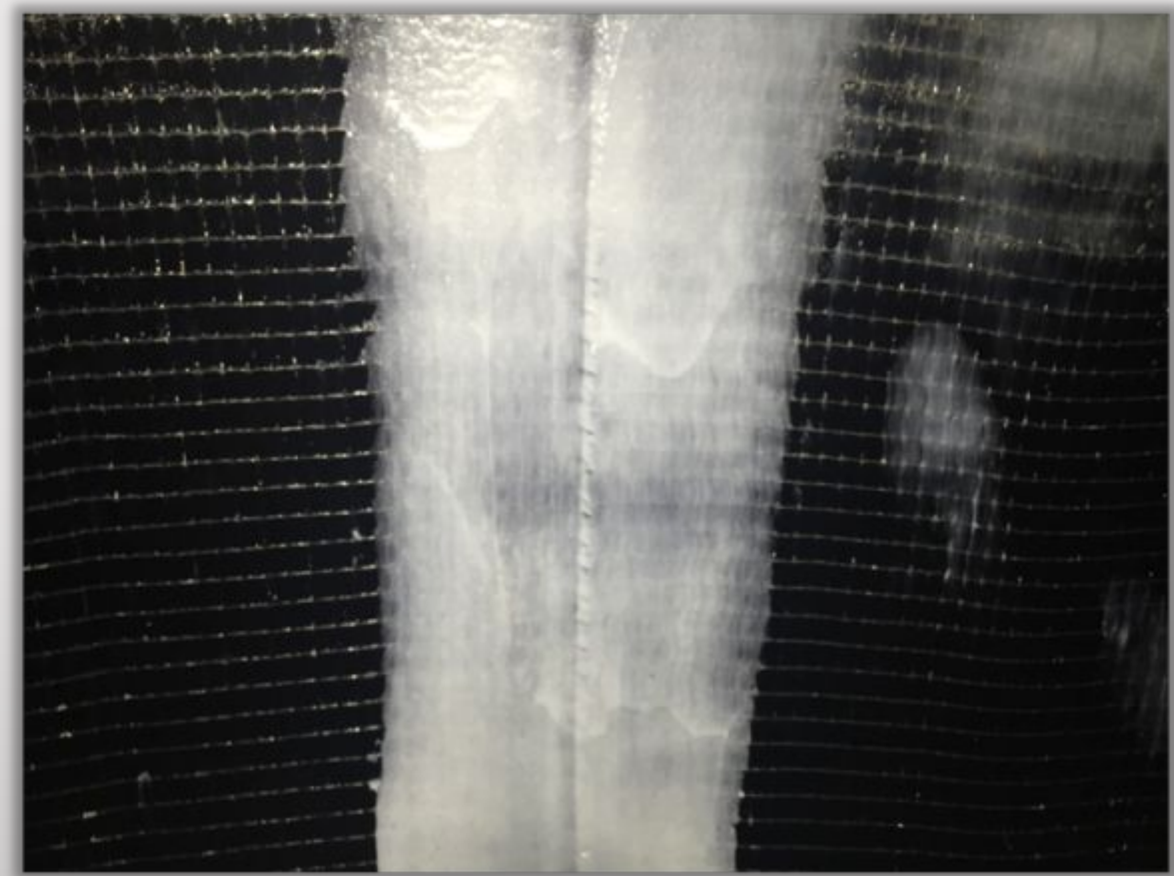
CFRP LINER INSTALLATION

CFRP layers at end detail

CFRP LINER INSTALLATION

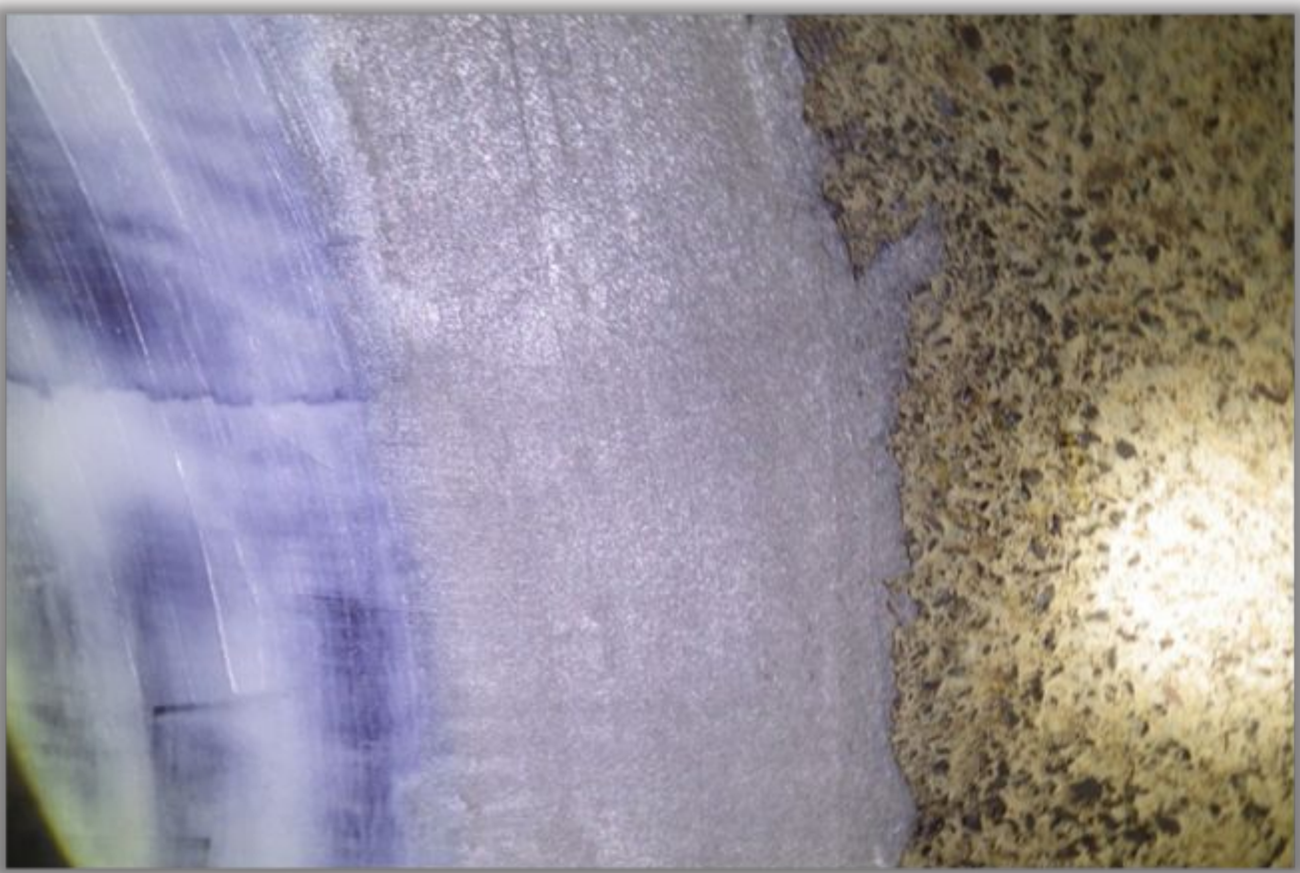
Installation of a watertightness layer

CFRP LINER INSTALLATION



Application of thickened epoxy to cover all edges and seams

CFRP LINER INSTALLATION



Epoxy mortar applied to end termination

CFRP LINER INSTALLATION

Completed CFRP lining

CONCLUSION

Likely causes of failure – based on site & lab inspection:

- Manufacturer defects (highly porous mortar coating, weak concrete core, use of 18 gauge steel cylinder instead of specified 16 gauge)
- Increased pressure from pipeline restart after power outage likely contributed to the timing of the pipe rupture

Emergency response

- Close coordination between multiple organizations to support pipeline inspection, failure investigation, and emergency repairs helped minimize downtime for this critical pipeline.
- CFRP lining provided an effective approach which minimized impact on the SCVWD and local residents

Thank you!

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