Corrosion Condition Assessments of Force Mains

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Corrosion Process
Internal & External Corrosion of Force Mains....
24” Ductile Iron Force Main

- Internal failure following loss of internal mortar lining
- Failure was along top of pipe due to formation of hydrogen sulfide gas
Dual 26” Force Mains

- Internal failures at bottom of pipe
- Failure following loss of internal mortar lining
- Failures concentrated at low areas (dips) in pipeline alignment
- Cause is corrosion under accumulated solids
36” Above Ground Crossing

- Failure of force main at above ground crossing
- Crown of pipe attacked by hydrogen sulfide gas
External Corrosion

- Caused by Aggressive soil conditions
- Galvanic Corrosion
- Stray DC Currents
External Corrosion Attack
Actual size of AWWA Specification Thickness Reductions
for 36-inch Diameter Cast and Ductile Iron Pipe - 1908 to Present
(150 PSI Operating pressure)
Cast Iron Pipe (thicker walled pipe)
External pitting (concentrated) corrosion attack on thinner walled ductile iron pipe.
Temporary Fix?
The rate and magnitude of corrosion depends on a number of factors:

- Pipe Material and Characteristics
- Operating Conditions
- Construction Methods
- Environment (age not a good primary metric)
- Internal or External Corrosion Attack
Initial development driven by federally regulated pipeline integrity rules

Methodology also quite applicable to water / wastewater
#1 Pre-Assessment:

- Define pipe segments by construction contracts and similar characteristics, e.g. material, construction practices

- Identify specific locations along the pipeline
  - Air Release Points/Man ways
  - Pipeline crossings
  - Known area where piping failures have occurred
#1 -Pre-Assessment Data Gathering & Planning:

- “Good listening” – operating history, criticality, consequences of failure
- Leak & Repair Records
- Pipe “Bone Yard”
- Coordination of Condition Assessment Efforts With Other Activities
  - Excavations
  - Repairs
- Project construction drawings and specifications
- Pipe materials and characteristics
  - Wall thickness
  - Pressure rating
  - Flow Rates
  - Air Release points/operational status
  - Coatings and Linings
- Bedding and backfill material
- As-built documentation
- Soil corrosivity, e.g. resistivity, pH, chlorides, moisture
- Adjacent utilities and crossings
- Sources of stray current corrosion
  - Nearby cathodic protection systems
  - Direct current powered transit systems
  - High voltage overhead AC power lines
#2 - Indirect Inspection:

Indirect Inspection techniques:

- In-Situ Soil Resistivity Measurements
- Soil Sample Collection and Analysis
- Ultrasonic Thickness Measurements (if applicable)
- Direct Examination of Exposed Pipe Sections
- Stray Current Evaluations
#2 - *Indirect Inspection:*

- Integrate all data along pipeline alignment
- Analyze Data and Rank Indications:
  - Severe
  - Moderate
  - Minor
- Select at sites for direct inspection – locations should be where corrosion activity is most likely
- Select control site where corrosion activity is the least likely
#3 - Direct Examination

- Excavating the pipe
- Performing physical inspection & photograph
- Evaluating integrity of coating/wrap, if present
- Testing the pipe surface, e.g. corrosion pitting
- UT measurements
- Measuring dimensions of corrosion defects
- Analyzing surrounding soil / groundwater
- Performing root cause analysis
<table>
<thead>
<tr>
<th><strong>Inspector name</strong></th>
<th><strong>Date</strong></th>
<th><strong>Address of pipeline inspection</strong></th>
<th><strong>Leak?</strong></th>
<th><strong>Yes</strong></th>
<th><strong>No</strong></th>
<th><strong>File Number:</strong></th>
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1. **Type of Pipe:**
   - cast iron _____
   - ductile iron _____
   - carbon steel _____
   - copper _____
   - carbon steel _____
   - non metallic _____
   - concrete _____
   - other _____

2. **Diameter of pipe:**
   - **Pipeline Name:**
   - **Service Type:**
     - Water _____
     - Wastewater _____
   - **Estimated date of pipe installation:**
   - **Depth of pipe:**

3. **Type of Pipe:**
   - Distribution _____
   - Transmission _____
   - Service _____
   - Hydrant _____
   - Mechanical joint _____
   - Fasteners _____
   - Other _____
   - Unknown _____

4. **Type of Coating:**
   - Polyethylene Encased _____
   - Shop applied coating _____
   - No Coating _____
   - Tape Wrap _____
   - Unable to determine _____

5. **External Pipe Condition:**
   - Very Good _____
   - Good _____
   - Poor _____
   - comments: ______________________________________________________________________________________

6. **Ultrasonic Thickness Measurements and comment:**
   - **Internal Lining Present:**
     - Yes _____
     - No _____
   - **Typical Size of Pits:**
   - **Quantity of pits:**

7. **Is graphitization evident (longitudinal or circumferential breaks):**
   - Yes _____
   - No _____

8. **Is the pipe installed in:**
   - Industrial area _____
   - Residential area _____
   - Rural area _____
   - Near street or road _____
   - Near creek or waterway _____
   - In reclaimed land _____
   - Near oil or gas pipelines _____
   - Near high voltage lines _____

9. **Describe soil conditions where inspection occurred:**
   - wet _____
   - dry _____
   - clay soil _____
   - rocky soil _____
   - cinders _____
   - other ____________________________________________________________________________________________

10. **Where soil samples obtained, sealed and analyzed for chlorides, moisture content, pH, sulfides, resistivity? If yes results were:**

11. **Were previous repairs made on the pipeline (leak clamps, etc):**
   - Yes _____
   - No _____

12. **Was a repair clamp installed on the pipe during inspection:**
   - Yes _____
   - No _____

13. **Describe any other comments:**
    _________________________________________________________________________________________________

14. **Plan of Action:**

15. **Insert digital photos below:**

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#3 - Direct Examination:

- When corrosion is found, perform a root cause analysis
- Implement localized corrosion protection
- Install instrumented test station for future assessment of corrosion activity, e.g. corrosion rate probes
#4 – Post Assessment:

- Calculate remaining life
  - Pit growth rate and wall thickness
  - Internal or External Corrosion
  - Coupons
  - Electrical resistance (ER) probes

- Maximize benefit by
  - Capture ideas for improvement
  - Determine need/timeframe for update evaluations
  - Identify corrective action options

![Graph showing corrosion rate and AC current over time]
#4 – Post Assessment Recommendations:

- Identify Corrective Options
  - Operational Procedures
  - Treatment Practices
  - Internal Lining
  - Cathodic Protection
  - Stray Current Mitigation
  - Pipeline Replacement
  - Pipeline Monitoring
Program for Existing Mains
Break Reduction Life Extension Through Cathodic Protection
Anode Lead Wire Connection

Galvanic Anode

Metallic Coupling

Cathodic Protection of Metallic Fitting
Meter Vaults

(Keep dry if possible)
Impressed Current CP System on Oil/Gas Lines can Create Stray Current Problem on Water Lines
Summary

- Effective management of force mains pipeline includes understanding and managing the risk of corrosion.
- A systematic approach to condition assessments results in the most value at the lowest cost.
- Retrofitting with accepted industry practice such as internal linings, treatment programs, operational adjustments, or cathodic protection may be a cost-effective option for extending the life of existing mains.
- A key asset management strategy is to include suitable corrosion control in the design of new force mains.
Other Structures
Thank You

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Prioritizing Distribution Systems
Program for Existing Mains
Break Reduction Life Extension Through Cathodic Protection

Anode Installation
100 Breaks Prior to Cathodic Protection
3 Breaks After Cathodic Protection

1988 C.P. Totals
Length Protected = 12,780 feet
Copper Service Connections
Stray Current
Polyethylene Encasement of Ductile Iron Pipe

- Follow DIPRA installation procedures
- Clean pipe before installing polywrap
- Repair tears or damage to encasement
- Engage an inspector to oversee installation
Insituform
Repair of Break Should Include Anode Installation

Completed Repair
Lower Stress Area (Cathode)

Threaded Bolt
Higher Stress Area (Anode)

Metallic Coupling

Stress Corrosion

Pipe
Polyethylene Encasement of Ductile Iron Pipe

- Follow DIPRA installation procedures
- Clean pipe before installing polywrap
- Repair tears or damage to encasement
- Engage an inspector to oversee installation
**Force Main Recommendations**

- Use coatings and cathodic protection for external corrosion control of steel and ductile iron pipe
- Replace pipe at failure sites with PVC, HDPE or fiberglass
- For long sections of deteriorated pipe, replace with PVC, HDPE or fiberglass, or, internally line with cured in place polyester resin (CIPP)
- Where metallic piping must be used, line with ceramic epoxy.
History of Iron Pipe

Cast Iron

- Introduced to North America during the 1800's and installed till the 1970's.
- Early on, statically cast process produced a thick walled, heavy pipe.
- No longer produced in North America.

Ductile Iron

- Introduced in 1955 as an improvement to cast iron.
- Centrifugal casting process produces a thinner walled, lighter pipe which is stronger and more ductile than cast iron.
Anode Installed on Metallic Fitting
Investigative Structure (Existing)

Corrosion Assessment

- Review of General Characteristics of Water System
- Review Break / Leak History
- Field Survey

- Data Analysis & Risk Management
- Priority Index (Identification of Opportunities to Reduce Replacement / Repair Costs)
Effectiveness of Well Designed Corrosion Management Programs

CUMULATIVE BREAKS

YEARS AFTER INSTALLATION

665 breaks projected without protection after 25 years

94 breaks after 17 years

Cathodic Protection applied at Year 17

3 breaks after 8 years
Value of Well Designed Corrosion Management Programs

**Benefit to Cost Ratios ($ saved/ $ spent):**

City of Houston, TX 8

Marin Water District, CA 9

East Bay MUD, CA - All Facilities 7

East Bay MUD, CA - Steel Pipelines 24

Chicago Area Utility 25

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Annualized Costs – 20 Yr. Cycle

Life Extension Cathodic Protection 58% less expensive than continuing with repairs
Existing Force Mains:

- Internal Corrosion is likely the leading cause of main breaks
- External Corrosion may also be a factor
#2 – Indirect Inspection: Non-Invasive Over-the-Line Techniques
Existing Force Mains: Condition Assessment

...need to cost effectively understand and manage pipeline condition and operational risk...

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Criticality

Objective 1: Thorough Understanding of High Risk Regions
Objective 2: Cost Effective Field Evaluation
The four fundamental elements of a successful coating system involve:

1. Material Selection
2. Specification
3. Application
4. Inspection
Technologies

- Material Selection
- Protective Coatings
- Cathodic Protection
- Stray DC Current Control
- AC Interference Mitigation
Multiple failures at Buffalo Bayou on bottom of pipe
Performed ultrasonic thickness measurements in lift station
Cases of failure are scouring and turbulent flow
Force Main Corrosion Mechanisms

- Oxidizing
  \[ \text{H}_2\text{S} \rightarrow \text{H}_2\text{SO}_4 \]

- Bacteria
- Sulfur

- \( \text{H}_2\text{SO}_4 \) severe corrosion

- Sewage and sulfides
- Oxidized S-compounds \( \rightarrow \text{H}_2\text{S} \)
- Sulfate-reducing bacteria
- Slime accumulation

- Daily average sewage level
- Silt

- Uneroded concrete
30” Ductile Iron

- Internal corrosion failure at crown of pipe.
- Hydrogen sulfide gas formed sulfuric acid which attacked the mortar coating and then the underlying metal surface.
$H_2S$ & Silt Accumulation May Cause Internal Corrosion Problem....
Piping Inspection Phases

1. Identification of Problem or High Consequence Areas

2. Field Study/Inspection

3. Post Assessment/Identify Corrective Options
Accurate leak records are an invaluable predictive tool.
#2 – Indirect Inspection: Data Integration for Non-Invasive Over-the-Line Techniques
#2 - Indirect Inspection:
Available decision-assisting tools, among others:
- DDM™ – Risk-based “Design Decision Model”
- MTCF^SM – “Mean Time To Corrosion Failure” Predictive Model
#3 - Direct Examination:

- Excavating the pipe
- Performing physical inspection
- Evaluating integrity of coating/wrap, if present
- Ultrasonic Testing of the pipe surface
- Measuring dimensions of corrosion defects
- Analyzing surrounding soil / groundwater
- Obtain coupon
- Performing root cause analysis
24” DIP & Steel

- Internal pipe failures along crown of pipe
- Failures following loss of internal mortar lining
- Cause is formation of hydrogen sulfide gas
#3 - Direct Examination:

Procedures for data collection

- Physical Examination
- Photographic Documentation
- Pipe-to-Soil Potential Measurements
- Bi-metallic Connections, e.g. services
- Soil, Bedding, Backfill and Groundwater Tests
- Coating Assessment (if applicable)
- Mapping and Measurement of Corrosion Defects
- Ultrasonic Thickness Measurements
- AC and DC Stray Current Measurements