Aging Outlet Conduits Through Earthen Dams

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The Most Important Length of Pipe in your System .... is the one through your Dam
Aging, Pressurized Conduits
Presentation Outline

- Background Info
- Potential Failure Modes
- Corrosion of Iron Pipes
- Inspection and Cleaning
- Risk Reduction
- Recommendations
Potential Failure Modes of Conduits through Earth Dams

- **PFM 1**: Erosion of Soils into a Nonpressurized Conduit
- **PFM 2**: Erosion by Flow from a Pressurized Conduit
- **PFM 3**: Erosion of Soils Along the Outside of a Conduit
- **PFM 4**: Erosion of Earthfill through Hydraulic Fracture Adjacent to a Conduit
Nonpressurized Conduit (Upstream Control)

Ref: FEMA 484
Pressurized Conduit (Downstream Control)

External Seepage and Earth Pressures

Internal Water Pressure

Ref: FEMA 484
PFM 1 — Internal Erosion of Soils through Defect in Non-pressurized Conduit.

Ref: FEMA 484
PFM 2: Erosion by Flow out of a Pressurized Conduit

Ref: FEMA 484
PFM 3 - Erosion along Interface between Conduit and Soil

Ref: FEMA 484
PFM 4 - Erosion through Fractures adjacent to Conduit

Ref: FEMA 484
Common PFMs – Iron Pipes

- Blowout Holes
- Circumferential Cracking
- Bell Splitting

Ref: NRCC
Common PFMs – Iron Pipes

- Longitudinal Cracking
- Bell Shearing
- Spiral Cracking

Ref: NRCC
Graphitization

- Selective dissolution of iron matrix
- Graphite flakes held together by iron oxide
- Appearance of undamaged material
- Little dimensional change
- Weaker, more brittle
- Alters metallic properties (thermal, electrical, etc)
Graphitization

Figure 5. Cross-section of ductile iron pipe showing graphitisation. (City of Ottawa)
Manufacturing Defects

Figure 6. Pit cast pipe showing porosity (black dots on cut metal surface). (City of Toronto)

Figure 8. Longitudinal flaw in spun cast pipe. (City of Ottawa)
Identifying Corrosive Potential

DIPRA’s 10-Pt Rating System

- Soil Resistivity
- pH
- Oxidation-Reduction Potential
- Moisture Content
- Sulfides

US Bureau of Reclamation

- Soil Resistivity

![Image of corrosion testing equipment]
# DIPRA 10-Point Corrosion Rating

Also in Standard C105/A21.5
ANSI/AWWA and ASTM A674

## TABLE 2 10-point soil test evaluation for iron pipe

<table>
<thead>
<tr>
<th>Soil Characteristics</th>
<th>Points*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistivity $\Omega \text{cm}^\dagger$</td>
<td></td>
</tr>
<tr>
<td>$&lt;1,500$</td>
<td>10</td>
</tr>
<tr>
<td>$\geq 1,500-1,800$</td>
<td>8</td>
</tr>
<tr>
<td>$&gt;1,800-2,100$</td>
<td>5</td>
</tr>
<tr>
<td>$&gt;2,100-2,500$</td>
<td>2</td>
</tr>
<tr>
<td>$&gt;2,500-3,000$</td>
<td>1</td>
</tr>
<tr>
<td>$&gt;3,000$</td>
<td>0</td>
</tr>
<tr>
<td>pH</td>
<td></td>
</tr>
<tr>
<td>0–2</td>
<td>5</td>
</tr>
<tr>
<td>2–4</td>
<td>3</td>
</tr>
<tr>
<td>4–6.5</td>
<td>0</td>
</tr>
<tr>
<td>6.5–7.5</td>
<td>0$\ddagger$</td>
</tr>
<tr>
<td>7.5–8.5</td>
<td>0</td>
</tr>
<tr>
<td>$&gt;8.5$</td>
<td>3</td>
</tr>
<tr>
<td>Redox potential $\text{mV}$</td>
<td></td>
</tr>
<tr>
<td>$&gt;+100$</td>
<td>0</td>
</tr>
<tr>
<td>$+50 - +100$</td>
<td>3.5</td>
</tr>
<tr>
<td>$0 - +50$</td>
<td>4</td>
</tr>
<tr>
<td>Negative</td>
<td>5</td>
</tr>
<tr>
<td>Sulfides</td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>3.5</td>
</tr>
<tr>
<td>Trace</td>
<td>2</td>
</tr>
<tr>
<td>Negative</td>
<td>0</td>
</tr>
<tr>
<td>Moisture</td>
<td></td>
</tr>
<tr>
<td>Poor drainage, continuously wet</td>
<td>2</td>
</tr>
<tr>
<td>Fair drainage, generally moist</td>
<td>1</td>
</tr>
<tr>
<td>Good drainage, generally dry</td>
<td>0</td>
</tr>
</tbody>
</table>

*10 points: corrosive to iron pipe; protection is indicated.
$\dagger$Based on water-saturated soil box. This method is designed to obtain the lowest and most accurate resistivity reading.
$\ddagger$If sulfides are present and low ($<100$ mV) or negative redox-potential results are obtained, three points should be given for this range.
Soil Resistivity and Pipe Design Life

<table>
<thead>
<tr>
<th>Resistivity</th>
<th>Corrosivity</th>
<th>Failures Have Been Reported in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1,000 ohm-cm</td>
<td>Extremely Corrosive</td>
<td>5 Years or Less</td>
</tr>
<tr>
<td>1,000 to 5,000</td>
<td>Very Corrosive</td>
<td>15 Years or Less</td>
</tr>
<tr>
<td>5,001 to 10,000</td>
<td>Corrosive</td>
<td>20 Years or Less</td>
</tr>
<tr>
<td>10,001 to 25,000</td>
<td>Moderately Corrosive</td>
<td>25 Years or Less</td>
</tr>
<tr>
<td>Over 25,000</td>
<td>Mildly Corrosive</td>
<td>Over 25 Years</td>
</tr>
</tbody>
</table>

July 2003 NACE Materials Performance
Estimate Lifespan Of Ductile Iron Pipes

- <10-Pt Rating: 375 yrs
- >10-pt Rating: 24 yr
- "Uniquely Severe Environments":
  - 9-yrs

DIPRA Research – Asphaltic Coated DIP
Moisture Content

- As MC increases, so does corrosion rate

- Corrosion rates are slower under saturated conditions (Less Exposure to $O_2$)
Corrosion Rates as Function Of Time

Ref: Bonds et al. 2005
DIP vs. CIP

Ref: Spickelmire 2012
Inspection Of Pressurized Conduits

Regulatory

Recommended to address dam safety issues

Often Required by Regulations

Technical/Operational

Dewatered Conduit

Difficult/Costly

Unsafe Conditions
PADEP Dam Safety Requirements

- Outlet works must be capable of releasing:
  - 70% of highest mean monthly inflow
  - Plus top 2 ft of reservoir storage in 24 hours

- Detailed inspections on regular intervals
  - (Generally 5 to 10 years)
Inspection

- Inspections can be accomplished by manned entry or with push-cameras or ROVs, depending on size.
Inspection

- Recommend: dewater pipe
  - Drain Reservoir
  - Install Bulkhead
  - Access to downstream end of pipe?
Difficult Access - Manifold System
Difficult Access – Vertical Bends

Flow
Bulkhead/Plug Types

- Steel Plate
Bulkhead/Plug Types

- Inflatable Plug
What Happens When the Limits Are Pushed?!
Turberculation: Friend or Foe?

- Remove to facilitate inspection
- May accelerate Corrosion
- Line Pipe
  - Sliplining or Cured In-Place Pipe
Pipe Cleaning - Jetting

- Pre-cleaning inspection must be performed

Based on results of this inspection, jetting pressures and angles, pace of jetting action, etc. can be established.
Pipe Cleaning – Pigging

- Adequate access
- Uniform pipe size
- Less effective for heavy turburation
Pipe Cleaning - Chaining

- Weigh damage potential to pipe
- Use in conjunction with slipline

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Non-destructive Testing

- Varying Degrees of Accuracy and Application
- Voids on outside of a conduit (from FEMA 484)
  - Self-potential
  - Resistivity
  - Seismic tomography
  - Ground penetrating radar
Non-destructive Testing

- Pipe thickness
  - Ultrasonic (need good contact)
  - Magnetic Flux (max 0.6”)
  - *Broadband Electromagnetics*

- New Technologies
  - Sensor sent through pipe to find potential leaks from pressurized pipes
Reducing Risk Of Failure

- Routine Inspection and Assessment
  - Early Detection is Critical
- Filter Diaphragm
- If Deteriorated Conduit:
  - Removal and Replacement
  - Slipline
  - Abandon In-Place
- Seepage Issues Near Conduits:
  - Grout to Treat Seepage Zone
  - But ONLY in Conjunction with Add’l Drains/Filters
Retrofit Conduits With Upstream Control
Case History

- Constructed 1879
- Pressurized CIP, No Concrete Encasement, Corroded
- Abandoned (Grouted) Conduit In-Place
- Constructed New Siphon Intake Structure on Abutment
Recommendations

- Evaluate Each Dam Site Independently
- Plan and Coordinate with Entire Project Team
  - Owner
  - Engineer
  - Regulators
  - Contractors
- Balance Technical, Practical, and Regulatory Constraints
- Develop an Appropriate Investigation/Repair Plan
Questions?
Risk Informed Decision Making

- Can be Used to Prioritize Investigations and Repairs
- Refer to Procedures Developed by Various Federal Agencies
- Consider Factors that Contribute to Failure and their Consequences:

<table>
<thead>
<tr>
<th>Conduit Type, Age, Encasement</th>
<th>Wall Thickness and Section Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defect Dimension</td>
<td>Pipe Coating</td>
</tr>
<tr>
<td>Soil Gradation and Erodibility</td>
<td>Soil Resistivity</td>
</tr>
<tr>
<td>Hydraulic Fracture</td>
<td>pH of Reservoir</td>
</tr>
<tr>
<td>Seepage Gradient</td>
<td></td>
</tr>
</tbody>
</table>