Aging Outlet Conduits Through Earthen Dams

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The Most Important Length of Pipe in your System ….

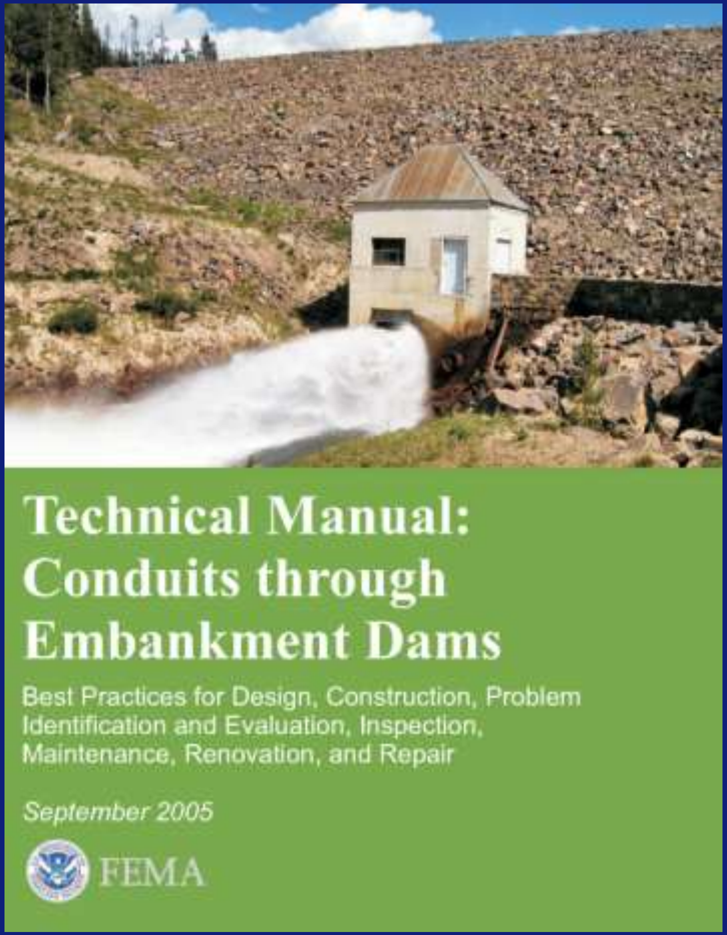
….is the one through your Dam

Aging, Pressurized Conduits

Presentation Outline

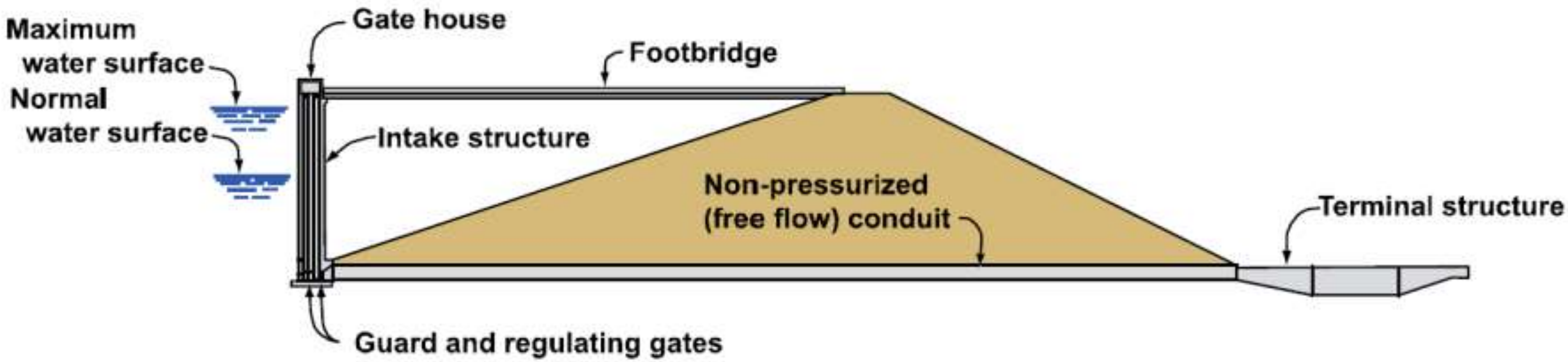
- Background Info
- Potential Failure Modes
- Corrosion of Iron Pipes
- Inspection and Cleaning
- Risk Reduction
- Recommendations

Potential Failure Modes of Conduits through Earth Dams



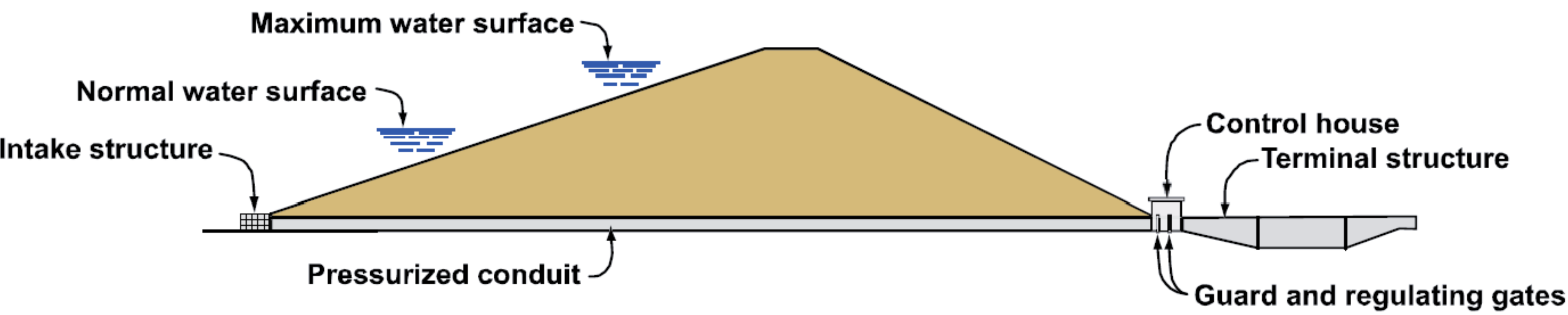
- **PFM 1: Erosion of Soils into a Nonpressurized Conduit**
- **PFM 2: Erosion by Flow from a Pressurized Conduit**
- **PFM 3: Erosion of Soils Along the Outside of a Conduit**
- **PFM 4: Erosion of Earthfill through Hydraulic Fracture Adjacent to a Conduit**

Nonpressurized Conduit (Upstream Control)

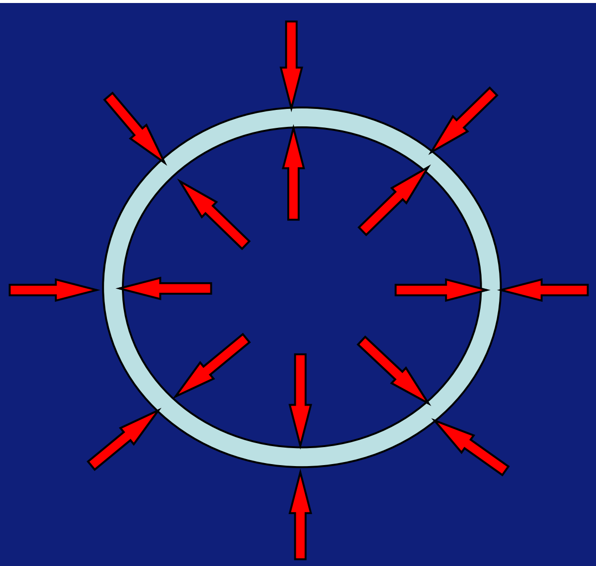


Ref: FEMA 484

Pressurized Conduit (Downstream Control)



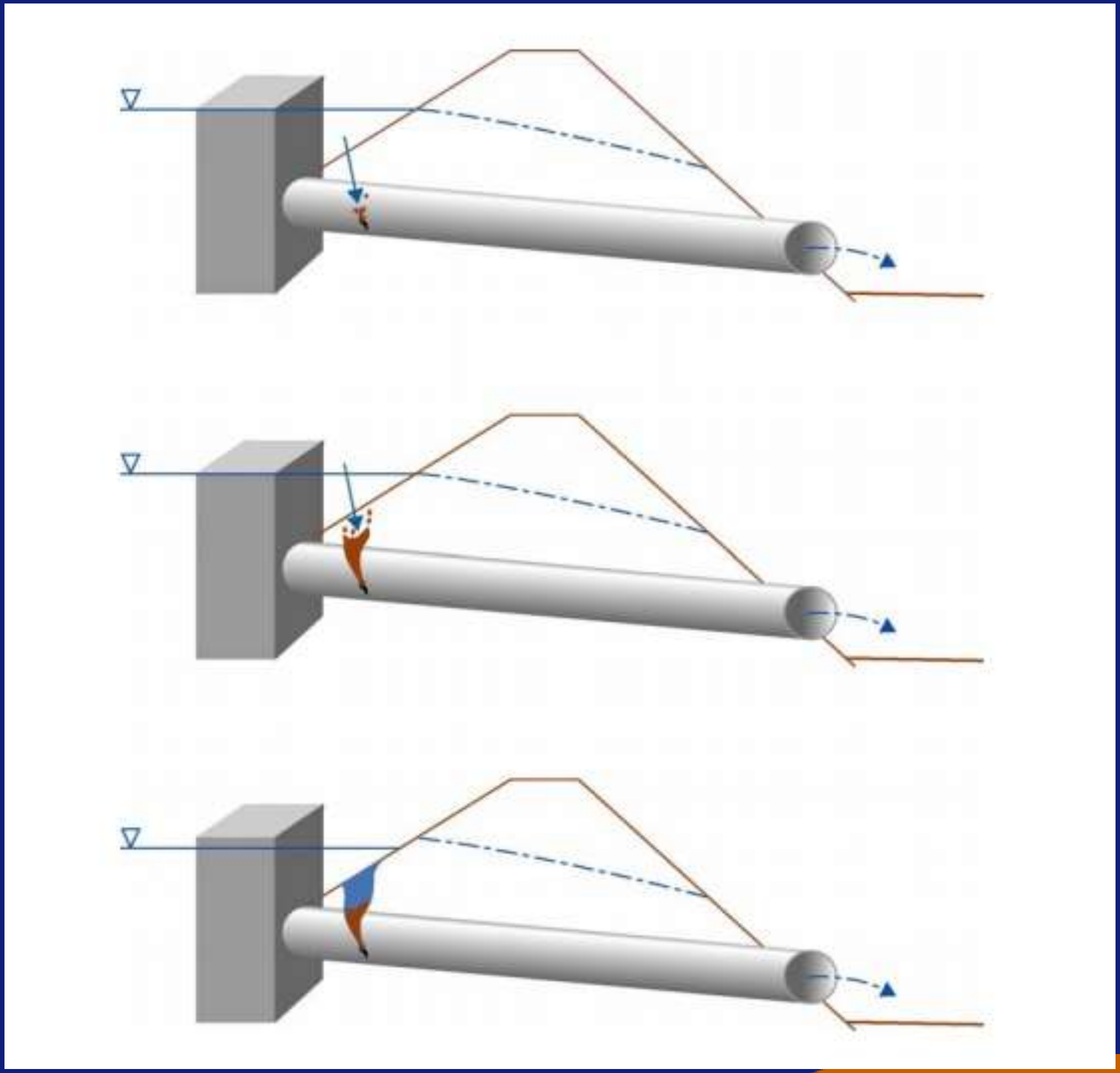
External Seepage and Earth Pressures



Internal Water Pressure

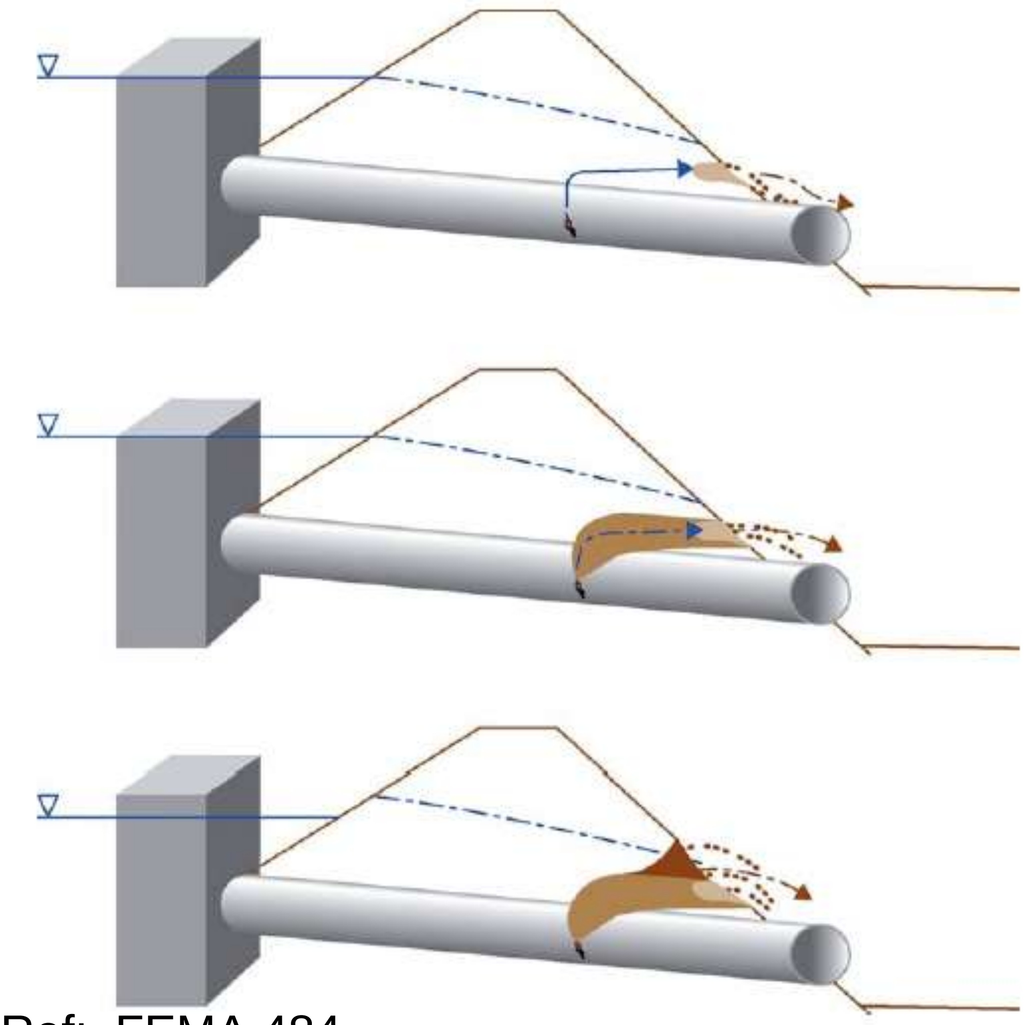
Ref: FEMA 484

PFM 1 —Internal Erosion of Soils through Defect in Non-pressurized Conduit.



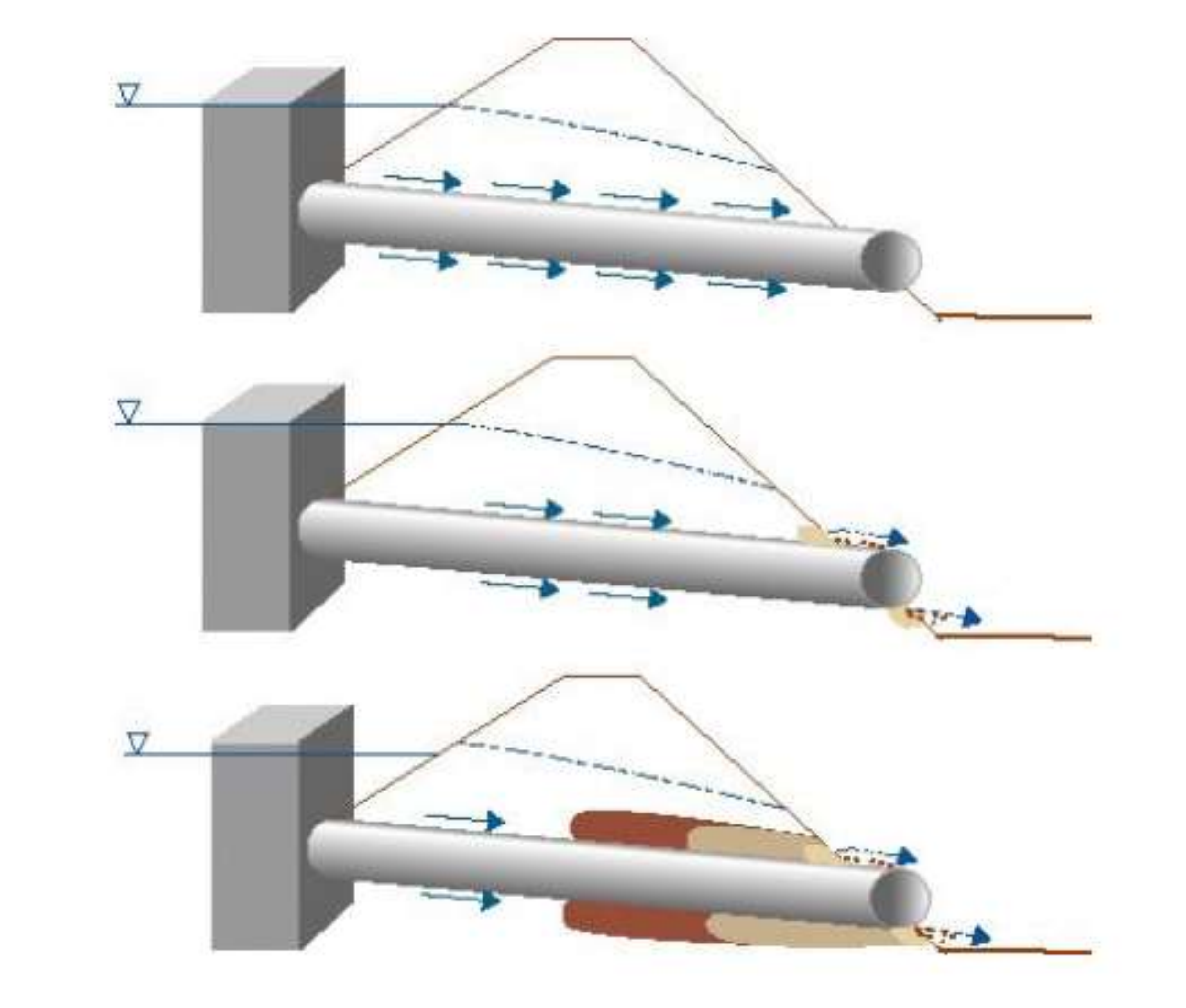
Ref: FEMA 484

PFM 2: Erosion by Flow out of a Pressurized Conduit



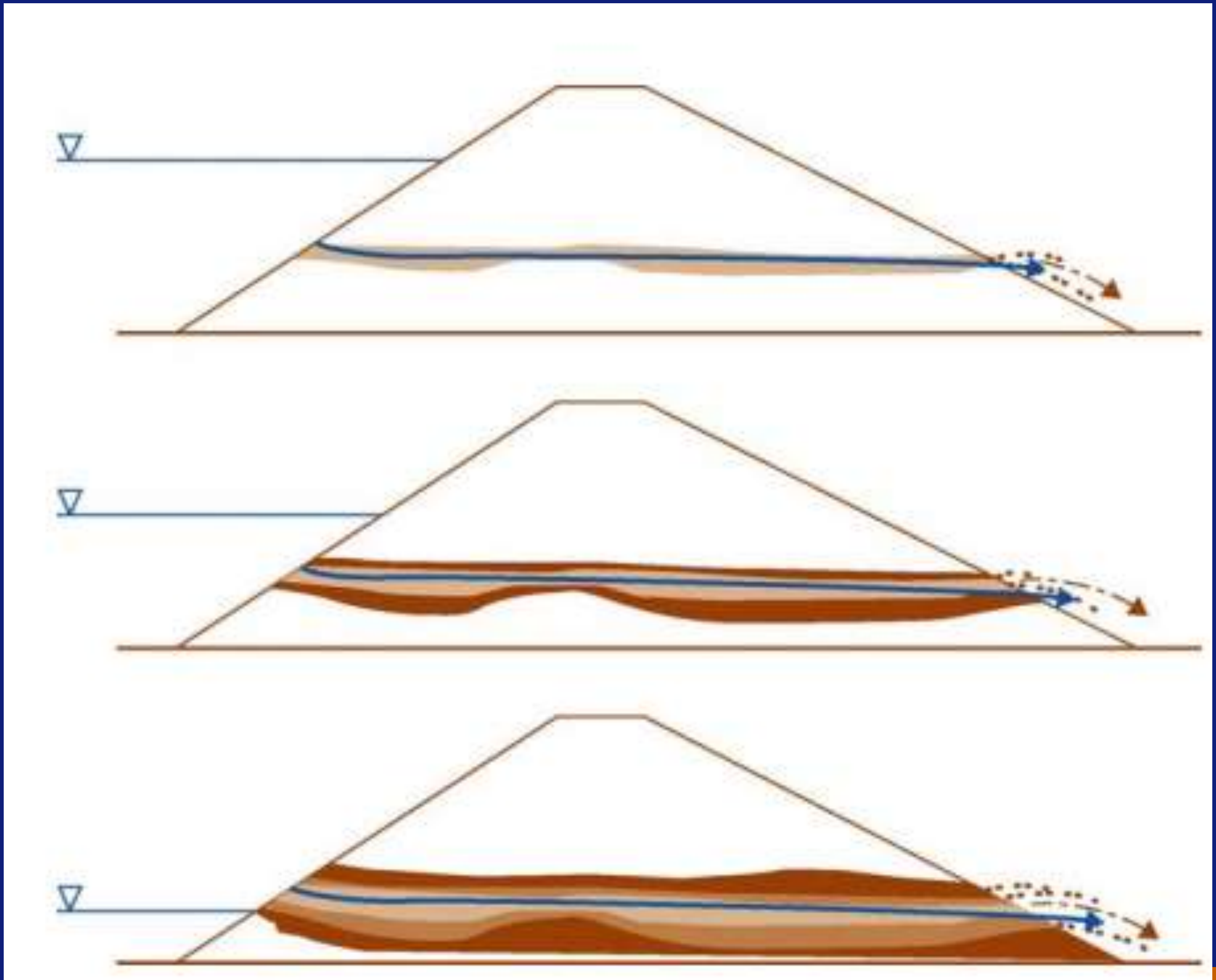
Ref: FEMA 484

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

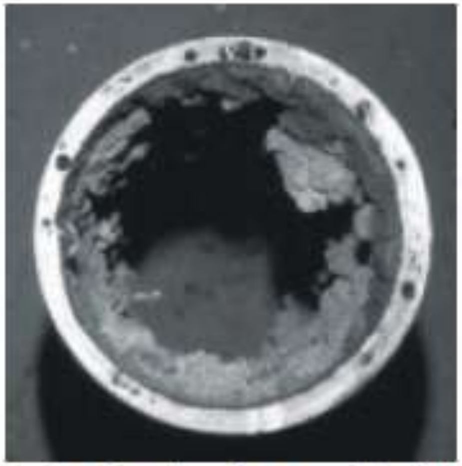


Figure 6. Pit cast pipe showing porosity (black dots on cut metal surface). (City of Toronto)

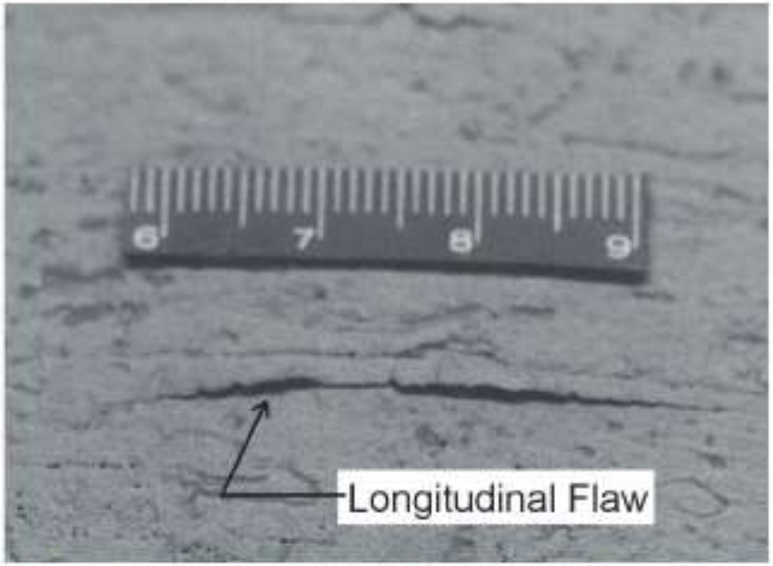


Figure 8. Longitudinal flaw in spun cast pipe. (City of Ottawa)

Identifying Corrosive Potential

- DIPRA's 10-Pt Rating System
  - Soil Resistivity
  - pH
  - Oxidation-Reduction Potential
  - Moisture Content
  - Sulfides
- US Bureau of Reclamation
  - Soil Resistivity

DIPRA 10-Point Corrosion Rating

TABLE 2 10-point soil test evaluation for iron pipe

Soil Characteristics	Points*
Resistivity—*Ωcm*†	
<1,500	10
≥1,500–1,800	8
>1,800–2,100	5
>2,100–2,500	2
>2,500–3,000	1
>3,000	0
pH	
0–2	5
2–4	3
4–6.5	0
6.5–7.5	0‡
7.5–8.5	0
>8.5	3
Redox potential—*mV*	
>+100	0
+50 – +100	3.5
0 – +50	4
Negative	5
Sulfides	
Positive	3.5
Trace	2
Negative	0
Moisture	
Poor drainage, continuously wet	2
Fair drainage, generally moist	1
Good drainage, generally dry	0

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

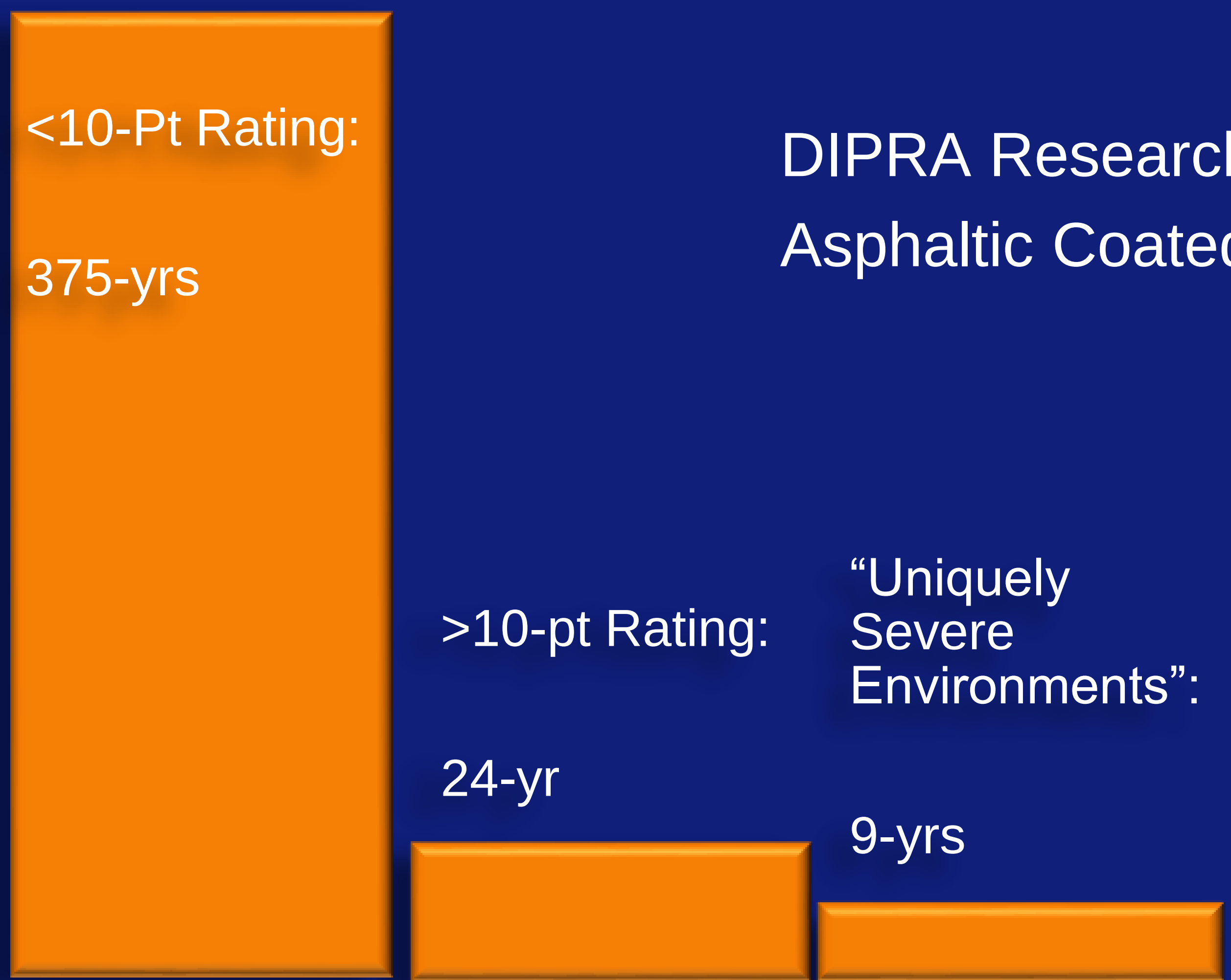
Also in Standard C105/A21.5 ANSI/AWWA and ASTM A674

Soil Resistivity and Pipe Design Life

Table 1 Resistivity Versus Corrosivity		
Resistivity	**Corrosivity**	**Failures Have Been Reported in**
Less than 1,000 ohm-cm	Extremely Corrosive	5 Years or Less
1,000 to 5,000	Very Corrosive	15 Years or Less
5,001 to 10,000	Corrosive	20 Years or Less
10,001 to 25,000	Moderately Corrosive	25 Years or Less
Over 25,000	Mildly Corrosive	Over 25 Years
July 2003 NACE Materials Performance		

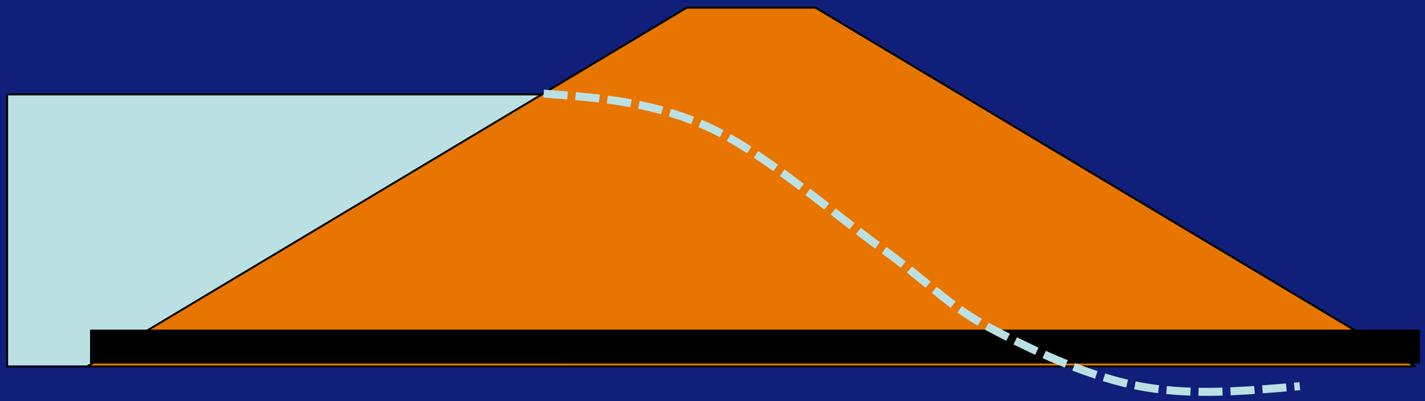
Estimate Lifespan Of Ductile Iron Pipes

DIPRA Research – Asphaltic Coated DIP

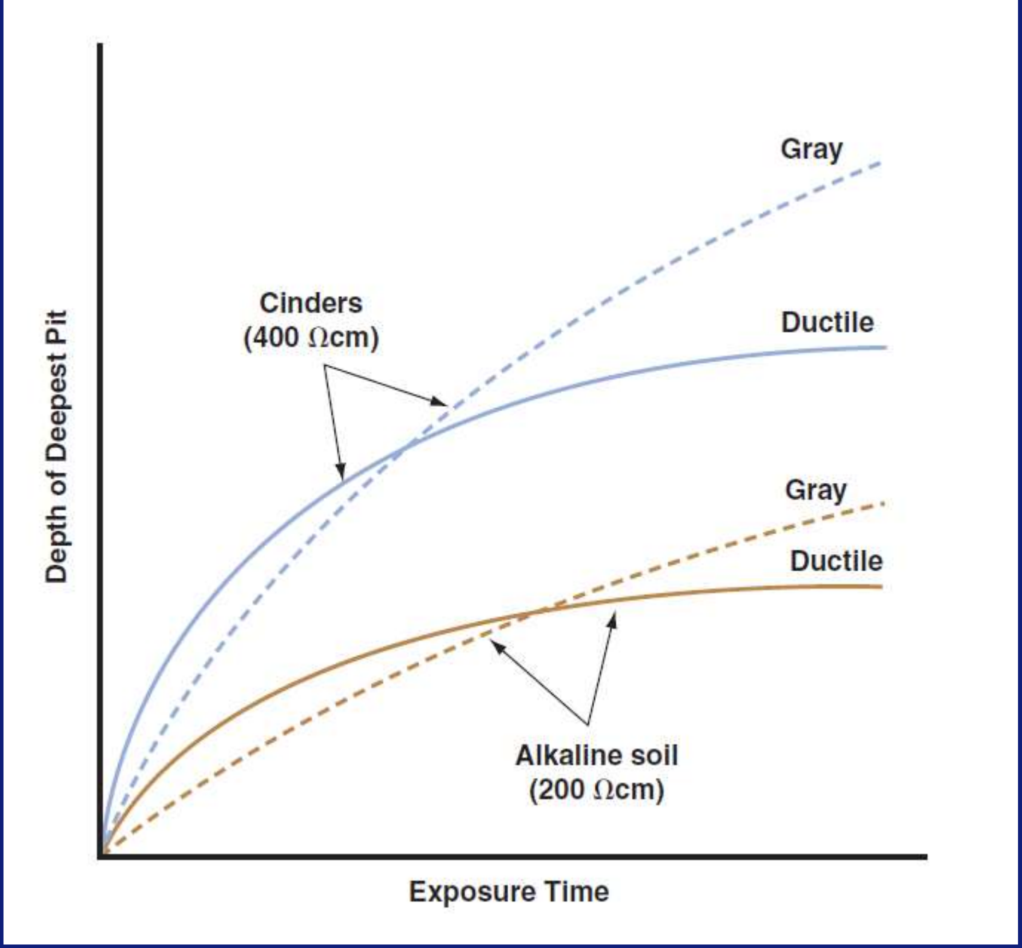


Moisture Content

- As MC increases, so does corrosion rate
- Corrosion rates are slower under saturated conditions (Less Exposure to O_2)

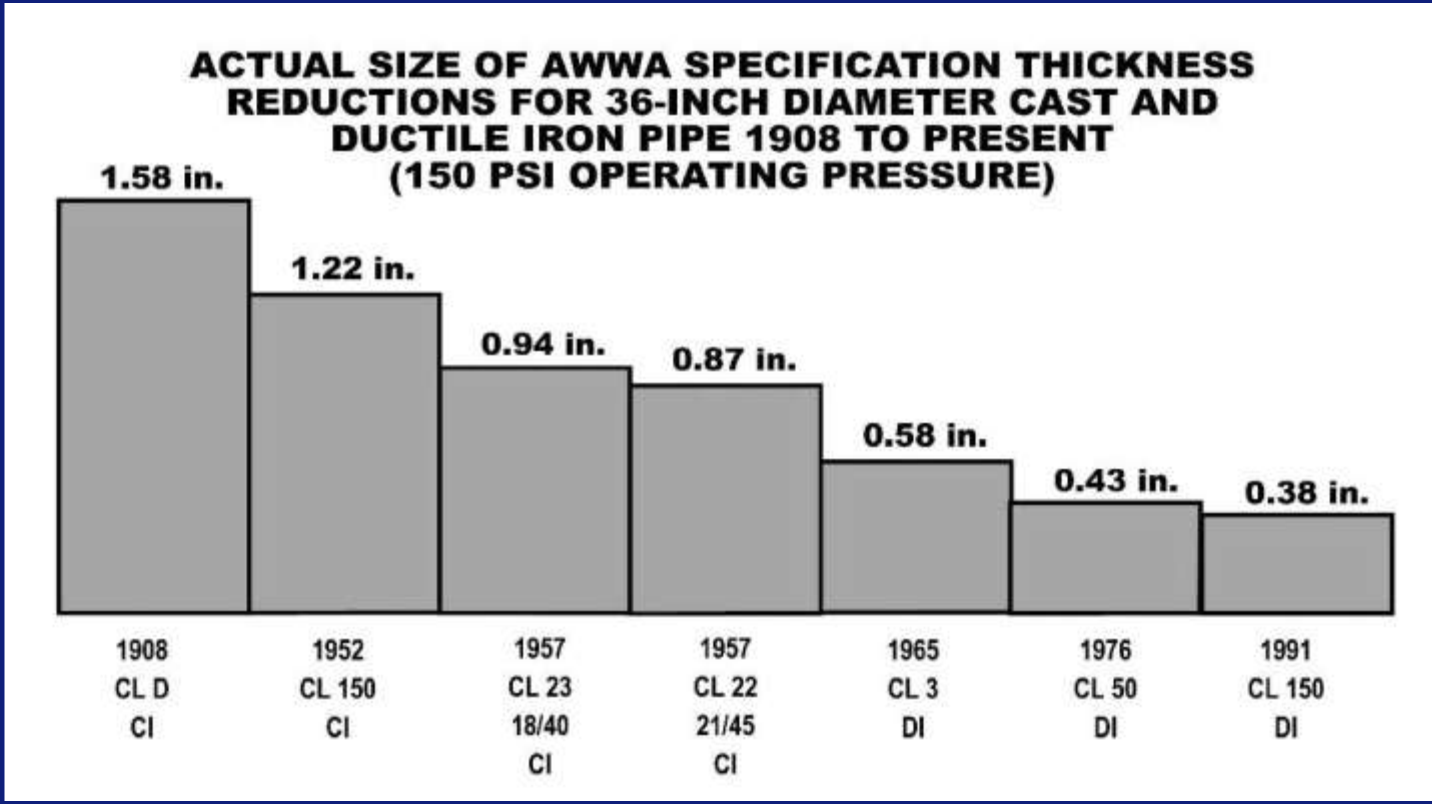


Corrosion Rates as Function Of Time



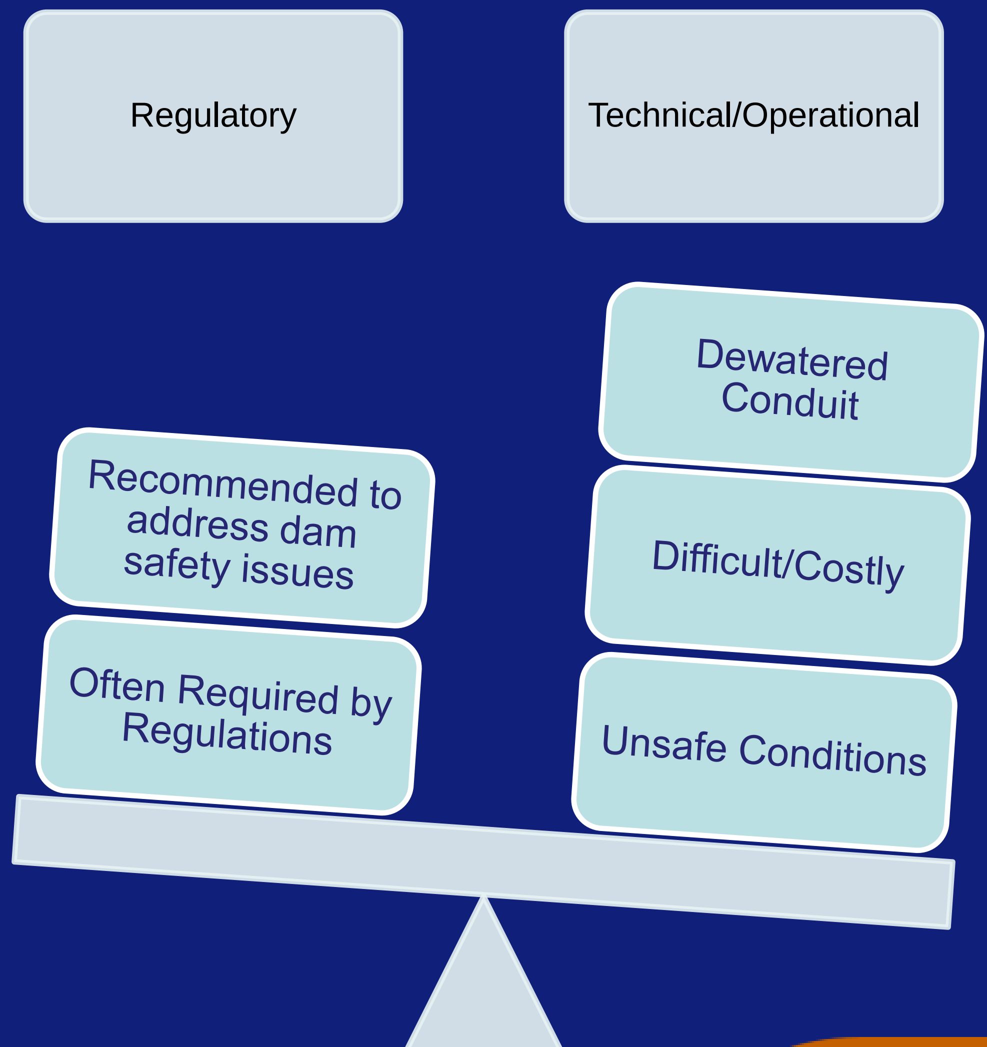
Ref: Bonds et al. 2005

DIP vs. CIP



Ref: Spickelmire 2012

Inspection Of Pressurized Conduits



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)

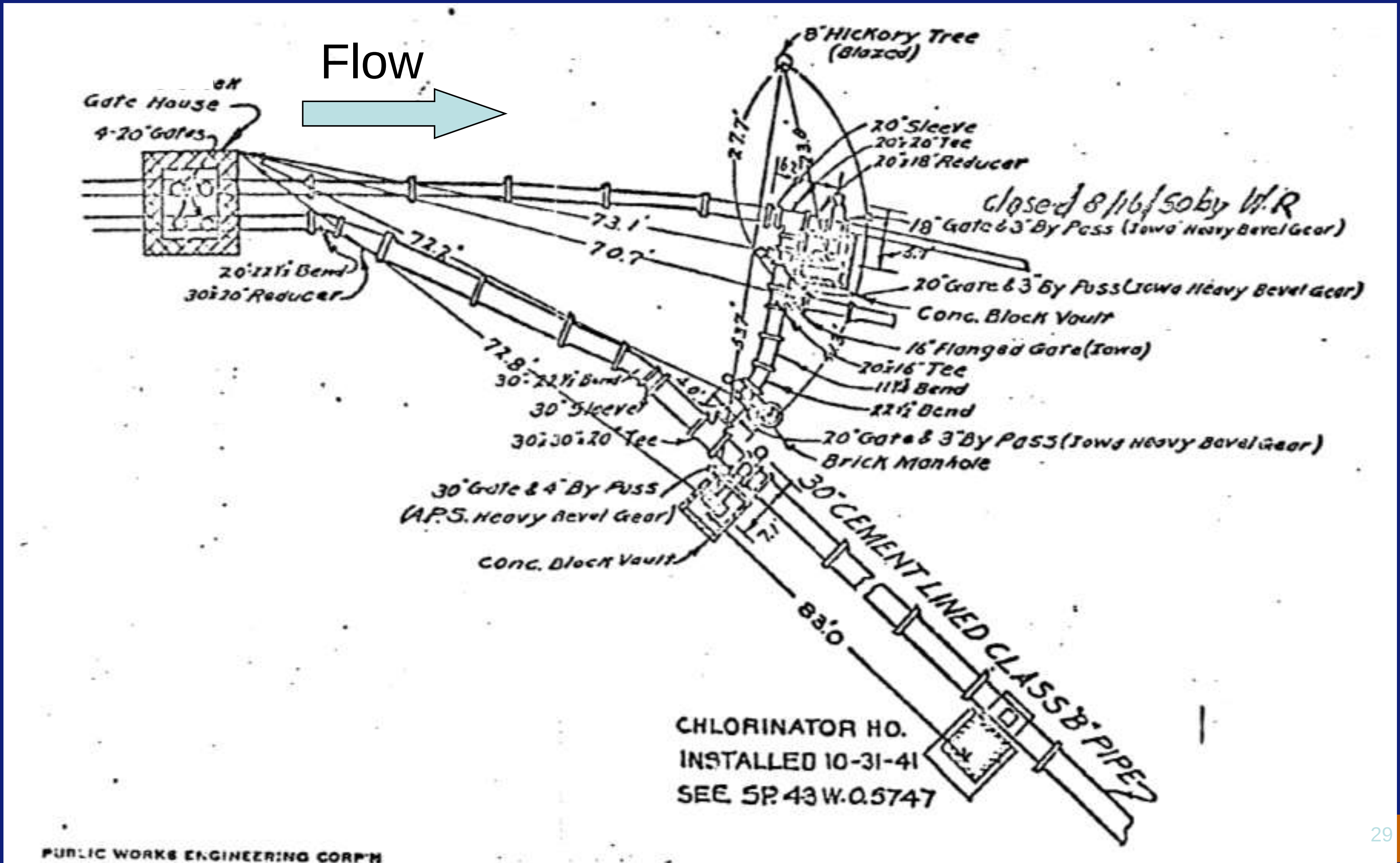
Inspection

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

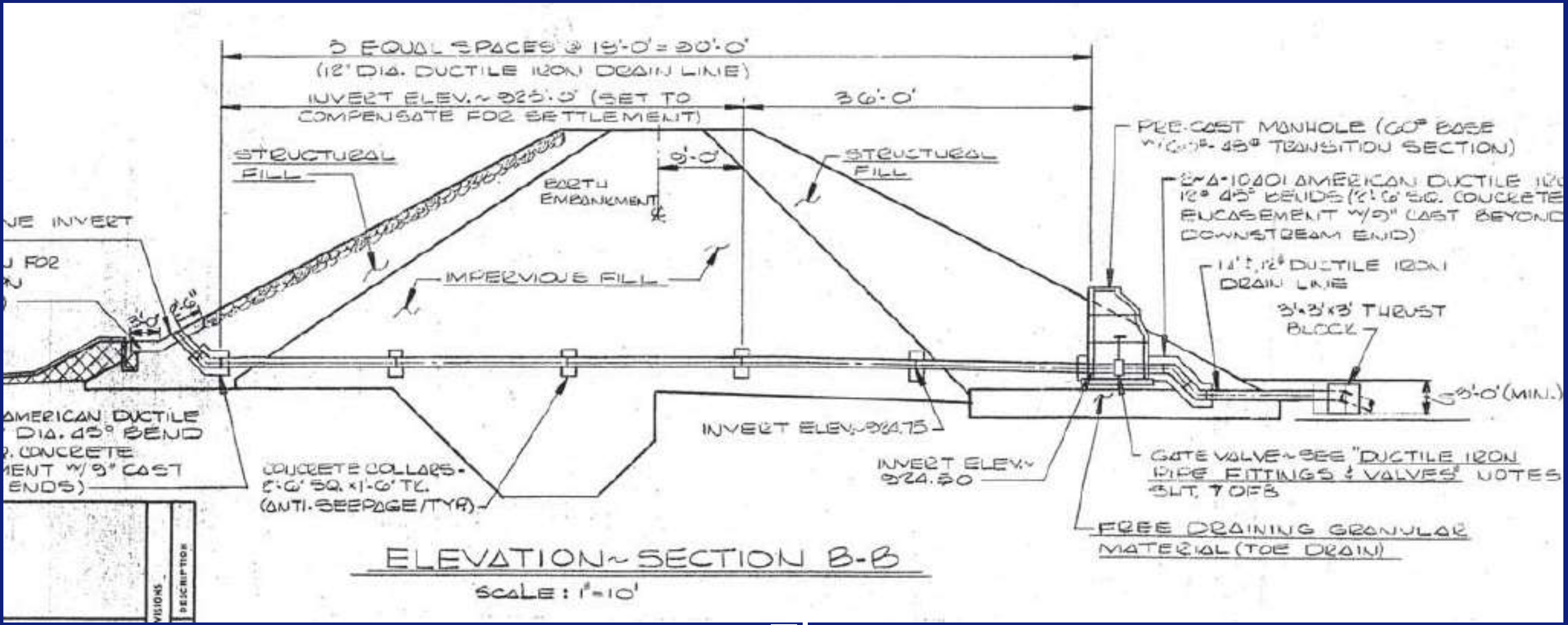
Inspection

- 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

Pipe Cleaning – Pigging

- Adequate access
- Uniform pipe size
- Less effective for heavy tuburculation

Pipe Cleaning - Chaining

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

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:

Conduit Type, Age, Encasement	Wall Thickness and Section Loss
Defect Dimension	Pipe Coating
Soil Gradation and Erodibility	Soil Resistivity
Hydraulic Fracture	pH of Reservoir
Seepage Gradient	