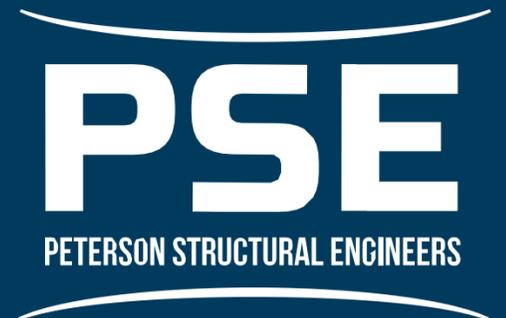


# Aging Water Storage Reservoir Evaluations: *Where Do I Begin?*

Presented by:

**Greg Lewis, PE** – *Peterson Structural Engineers*

**Nathan Rostad, PE, PMP** - *Murraysmith*





# Agenda

- 1 Why Evaluate?
- 2 Where to Begin
- 3 Inspections & Analysis
- 4 What to Do with All that Data
- 5 Q&A



# **Why Evaluate?**

# Reservoir Evaluations – Why?

- ✓ Properly functioning water storage facilities are vital to reliable water service in most systems
- ✓ Service life of properly maintained reservoirs can be >100 years
- ✓ Deferred maintenance can result in larger scale rehabilitation needed or unexpected failure – leaving a water system with deficient storage

# Reservoir Evaluations – Why?

- ✓ AWWA recommends evaluating every 5-10 years
- ✓ Track asset condition over time
- ✓ Structural improvements / strengthening to address code changes
- ✓ Prioritize CIP expenditures
- ✓ Assist with grant applications for funding repairs
- ✓ Assist with FEMA claim – was damage caused by the event or pre-existing?

# Reservoir Evaluations – Why?



Source: DYK Report, 5.0 MG Pritzker Brand Tank Evaluation, March 1999

Source: [https://www.pnws-awwa.org/uploads/PDFs/conferences/2015/Technical%20Sessions/Friday/5\\_Effective%20Water%20Storage%20Tank%20Inspections.pdf](https://www.pnws-awwa.org/uploads/PDFs/conferences/2015/Technical%20Sessions/Friday/5_Effective%20Water%20Storage%20Tank%20Inspections.pdf)



**Where to Begin?**

# Getting Started – What are your requirements?

What is going to be your evaluation methodology?

- ✓ What information can you gather or are unable to gather?
- ✓ How is your water system projected to change?
- ✓ How much does your storage inventory vary?



Steel



Prestress



Reinforce Concrete

# Evaluation Objectives – Quantify the System

Items that might be considered important:



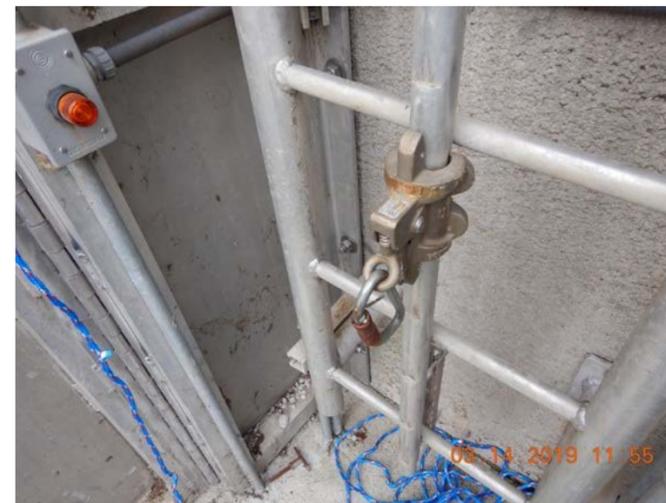
**Structural Performance**



**Water Quality**



**Corrosion**



**Safety**

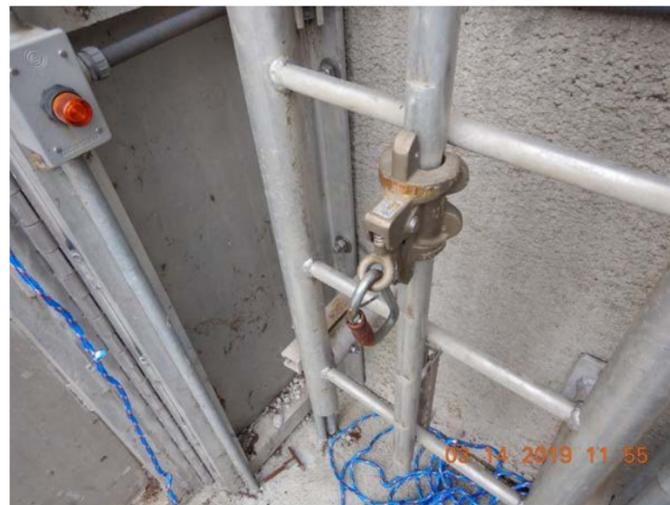
# Evaluation Objectives – Quantify the System

Items that might be considered important:



**Structural Performance**

*The adequacy of your structural system can change over time – age can impact the structure but also the Codes evolve.*



**Safety**

*Safety and Health considerations change over time – OSHA and other requirements are updated, safety devices can experience product recalls.*

# Evaluation Objectives – Quantify the System

Items that might be considered important:



*These elements are all important in their own way.*

*How does one evaluate these disparate items relative to one another?*



**Corrosion**

## Deferred Maintenance Risk Event

Coating Failure



Corrosion



Structural Deterioration

# Data Collection – Existing Documents

- ✓ Gather existing documents & reports
- ✓ Collating and organizing documents is key
- ✓ Confined Space and Hazard Abatement Information

**RECORD DRAWING**  
SEE DISCLAIMER,  
SHEET 1.  
VERSION 4.1  
12-9-97

**murraysmith**

**RECORD DRAWINGS**  
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VERSION 4.1, 12-9-97

**INDEX OF DRAWINGS**

GENERAL	
1	D-1 TITLE SHEET, INDEX OF DRAWINGS & VICINITY MAP
2	D-2 ABBREVIATIONS, LEGEND & SYMBOLS
3	D-3 GENERAL NOTES
4	D-4 SURVEY CONTROL

CIVIL	
5	C-1 EXISTING SITE, EROSION CONTROL AND DEMOLITION
6	C-2 EROSION CONTROL NOTES AND DETAILS
7	C-3 SITE PAVING PLAN
8	C-4 SITE PAVING PROFILES
9	C-5 CITY STANDARD DETAILS
10	C-6 DETAILS
11	C-7 TESTING AND FINAL CONNECTION CONFIGURATIONS

STRUCTURAL	
12	S-1 GENERAL STRUCTURAL NOTES
13	S-2 1.5 MG ROOF RETROFIT & DETAILS
14	S-3 1.5 MG ROOF UPGRADE LAYOUT AND GENERAL PENETRATION DETAILS
15	S-4 1.5 MG LADDER, LANING AND GENERAL DETAILS
16	S-5 3.0 MG UPGRADES & 1.5 MG & 3.0 MG MISC DETAILS

MECHANICAL	
17	M-1 1.5 MG & 3.0 MG VENTS AND 1.5 MG LADDER EXTENSION
18	M-2 1.5 MG & 3.0 MG OVERFLOW IMPROVEMENTS
19	M-3 RESERVOIR MISCELLANEOUS DETAILS - 1
20	M-4 RESERVOIR MISCELLANEOUS DETAILS - 2

CATHODIC PROTECTION	
21	CP-1 CATHODIC PROTECTION SYSTEM INSTALLATION OVERVIEW
22	CP-2 CATHODIC PROTECTION SYSTEM INSTALLATION DETAILS

**VICINITY MAP**  
SCALE: 1"=1,500'

**LOCATION MAP**  
SCALE: 1"=800'

**811**  
Know what's below.  
Call before you dig.

**murraysmith**  
2707 COLBY AVENUE, SUITE 1100  
EVERETT, WA 98201  
P 425.255.0000

1540715.010

# Data Collection – Existing Documents

- ✓ Tracked elements can be reviewed and compared to current conditions



# Data Collection – Developing Documents

- ✓ Create a record of inspection if none exists
  - AWWA D110 *Section 6.4 Routine Inspection* (for Prestress and Concrete\*)
  - API 653 Tank Inspection, Repair, Alteration, and Reconstruction
  - AWWA M42, SSPC VIS 2, AWWA D106 (Cathodic Protection, Anode Systems)

## 6.3.2 External Inspection

**6.3.2.1** All tanks shall be given a visual external inspection by an authorized inspector. This inspection shall be called the external inspection and must be conducted **at least every 5 years** or  $RCA/4N$  years (where  $RCA$  is the difference between the measured shell thickness and the minimum required thickness in mils, and  $N$  is the shell corrosion rate in mils per year) whichever is less. Tanks may be in operation during this inspection.

TANK IN-SERVICE INSPECTION CHECKLIST		
Item	Completed ✓	Comments
<b>C.1.1 FOUNDATION</b>		
Measure foundation levelness and bottom elevations (see Appendix B for extent of measurements).		
<b>C.1.1.1 Concrete Ring</b>		
a. Inspect for broken concrete, spalling, and cracks, particularly under backup bars used in welding butt-welded annular rings under the shell.		
b. Inspect drain openings in ring, back of waterdraw basins and top surface of ring for indications of bottom leakage.		
c. Inspect for cavities under foundation and vegetation against bottom of tank.		
d. Check that runoff rainwater from the shell drains away from tank.		
e. Check for settlement around perimeter of tank.		

# Developing Consultant Team

- ✓ Civil
- ✓ Structural
- ✓ Coating/Corrosion
- ✓ Geotechnical

*Consider areas of concern in determining your consultant team.*



# Additional Consultant Team Members

Confirm your documentation trail. If a design analysis is to be conducted, a key item is as-built drawings.



*Destructive Testing*

**Prestress and Concrete** are usually built to plan. Drawings are a must for an accurate assessment.



*PMI – Positive Material Identification Gun*

**Older steel reservoirs** tend to be “built per spec.” Drawings are usually missing or schematic. Advanced non-destructive testing can eliminate many questions.

# Preliminary Scoring System Development

- ✓ Develop a list of items to be evaluated.
- ✓ Stakeholder input can be valuable.

*Example of how different Owners tailored subcategories to their specific needs.*

## *Client A*

Piping/Valving	Inlet Piping
	Outlet Piping
	Drain Piping
	Overflow Piping
	Washdown Piping
	Attached Valve Vault Structure
	Control Valving
	Isolation Valving

## *Client B*

Site Piping	Seismic Valves (Valve, actuator, sensor, batteries)
	Inlet piping
	Outlet piping
	Underdrain System
	Overflow Piping
	Reservoir Drain Piping
	Flexible connections at foundation
	Isolation valving at foundation

# Define Scoring Criteria

*Good  
Condition*



*Poor  
Condition*

Criteria	5	4	3	2	1
<b>Code / Standard Conformance Score</b>	Meets Relevant Codes / Standards	Doesn't meet suggested best practices	Doesn't meet current code, but in compliance	Doesn't meet current code, and upgrades recommended	Does not meet code, not in compliance
<b>Coating</b>	Good condition (<1% exposed)	5% loss of any coating layer or visual blistering, spot repair defects the next time the tank is drawn down.	10% loss of any coating layer. Repair coating damage within 5 years.	20% loss of any coating layer, most likely full recoat within 5 years.	> 20% coating loss, Poor Condition / Full Recoat within 3 years.
<b>Corrosion</b>	Good condition, isolated rust staining (<1% exposed)	Rust staining and general surface corrosion between 1 and 5% of surface area. Pitting depth < 5% of nominal wall thickness.	Widespread rust staining and general surface corrosion between 5 and 20% of surface area. Pitting depth between 5 and 10% of nominal wall thickness.	Heavy rust staining and widespread general surface corrosion over 20% of surface area. Pitting between 10 and 20% of nominal wall thickness.	Rust staining and general surface corrosion over 20% of surface area. Pitting > 20% of nominal thickness.
<b>Structural Performance - Static Score</b>	Code Compliant with Minimal Issues*	Code Compliant with Some Issues*	Not Code Compliant but no structural defects*	Structural defects noted that could require extensive upgrade*	Critical Structural defects noted that require immediate repair*
<b>Structural Performance - Seismic Score</b>	Code Compliant with Minimal Issues*	Code Compliant with Some Issues*	Not Code Compliant but no structural defects*	Structural defects noted that could require extensive upgrade*	Critical Structural defects noted that require immediate repair*

# Define Scoring Criteria

Criteria	5	4
<b>Corrosion</b>	Good condition, isolated rust staining (<1% exposed)	Rust staining and general surface corrosion between 1 and 5% of surface area. Pitting depth < 5% of nominal wall thickness.

3	2	1
Widespread rust staining and general surface corrosion between 5 and 20% of surface area. Pitting depth between 5 and 10% of nominal wall thickness.	Heavy rust staining and widespread general surface corrosion over 20% of surface area. Pitting between 10 and 20% of nominal wall thickness.	Rust staining and general surface corrosion over 20% of surface area. Pitting > 20% of nominal thickness.



# **Inspections & Analysis**

# Inspections & Analysis

Inspection will serve to gather needed information; confirming as-built conditions and to perform non-destructive or destructive testing.



**PSE**  
PETERSON STRUCTURAL ENGINEERS

Built: 1969  
Overflow: 50'  
Typ. Operation: 45' - 50'

**WELDED STEEL RESERVOIR SITE INSPECTION**

Project #: 1802-0019 Project Name: Marietta 3.0 MG  
Site Visit Date: 1/24/19 Reservoir Type: Steel  
Site Conditions: Overcast, cloudy wet grass  
1404 Marietta Ave

**Exterior Inspection** 50' wall height

Number of Steel Shell Courses: 6 Standard Height  
Shell Course Height: (top) 10', 8', 8', 8'  
Knuckle yes (no) Radius N/A Thickness N  
Shell Course Thicknesses: (top) 11/16", 0.5687", 15/32", 3/4"

Condition of Exterior Shell and Coatings (check for loss)  
Con good, nochaste shedded an was incidental, coating loss from rec  
Weld lines not smooth in most to rough

List location of all external items (pipes, manways, ladders using pace count method.)

Condition of Ladder/Vents/Hatch/Welds: Ladder (Extera attachment points. Hatch, 1 hatch 24" dia cond. with staining. Welds most are corrosion. Ladder

Manway Dia: 24", Ladder Dimensions 16" wide 1"

Question:  
 Operating range  
 Foot size  
 No ladder by hatch, will need wirth fo

**RC CONCRETE (RETANGULAR) RESERVOIR SITE INSPECTION**

**PROJECT NAME:** Bellingham Res. Eval  
**PROJECT NUMBER:** 1802-0019

**RC CONCRETE (RETANGULAR) RESERVOIR SITE INSPECTION**

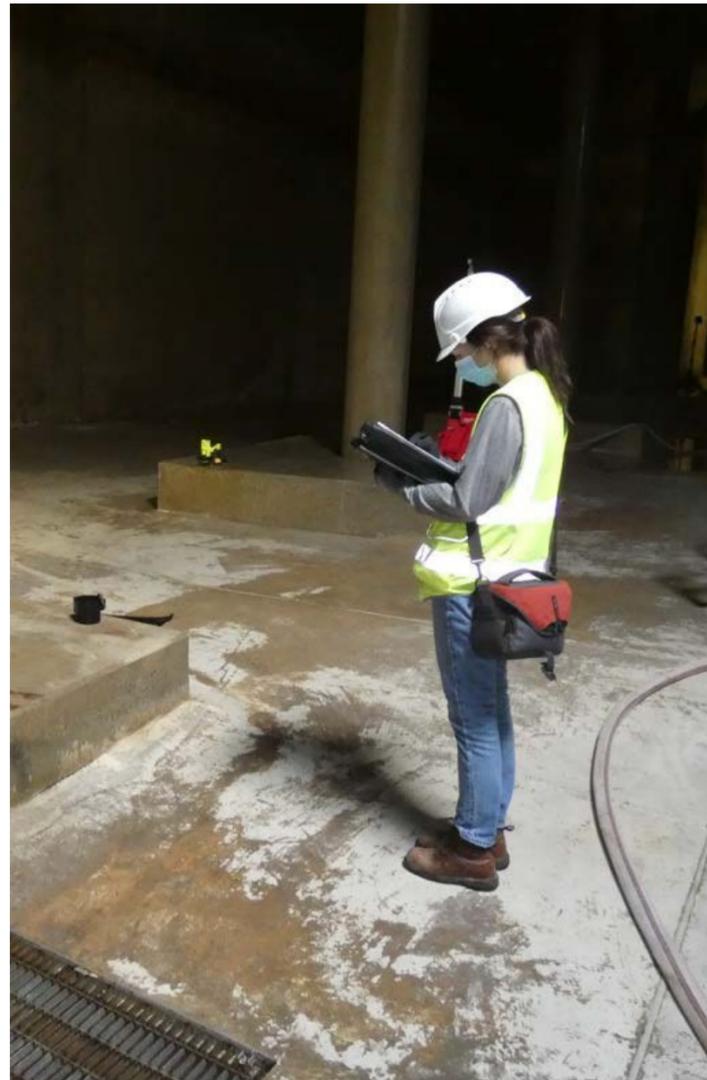
Project Name: Schome, 0.7 MG  
Site Visit Date: 1/24/19 Reservoir Type: Concrete w/ buttress walls  
Temperature and weather: Overcast, wet, 46°F  
Site Conditions: Muddy, heavily forested, lots of material (leaves etc.) on top of res. Before cleaning at least a foot of built-up material on top of res.  
PSE Staff: Greg L.  
Client/Other Staff: Matt Harding MSA

Overflow: 14'  
Operating: 10' - 13'

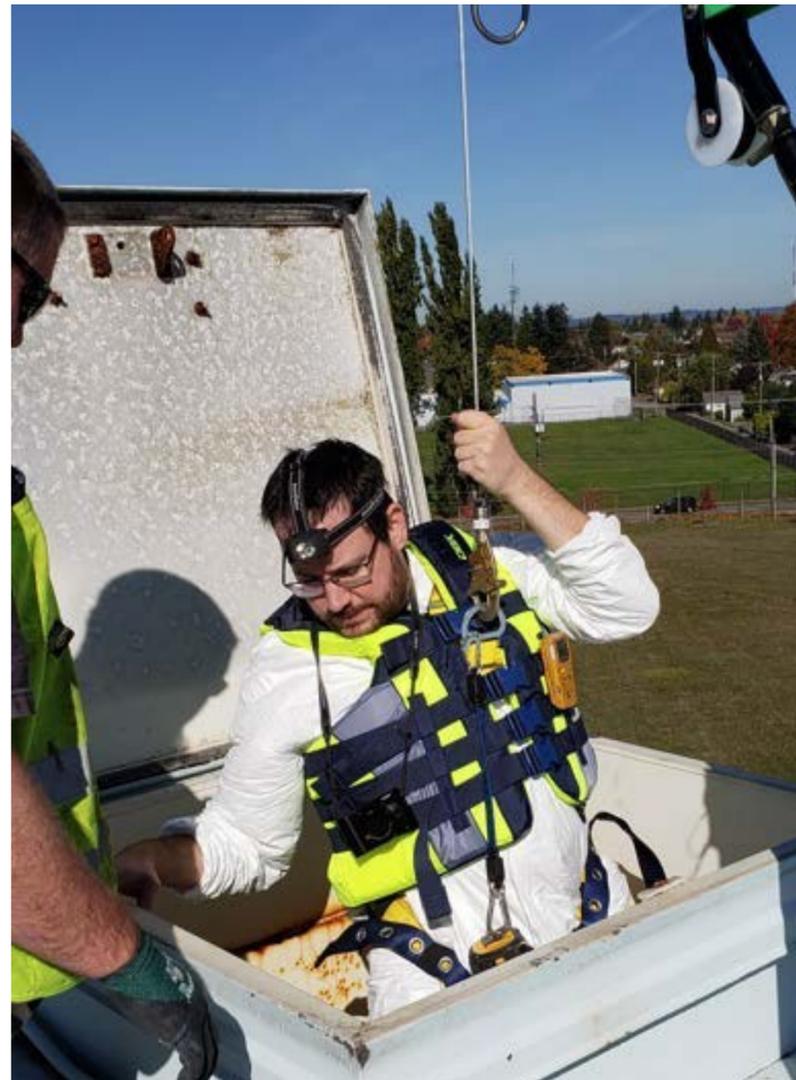
Drawing show original tank. Addition of new rest add columns & ±3.5 ft of new Wall height to sides of reservoir.

# Inspection Timing

What do you want evaluated and when can this be accomplished?



**Drained Reservoir Eval.**  
*During non-peak demand*



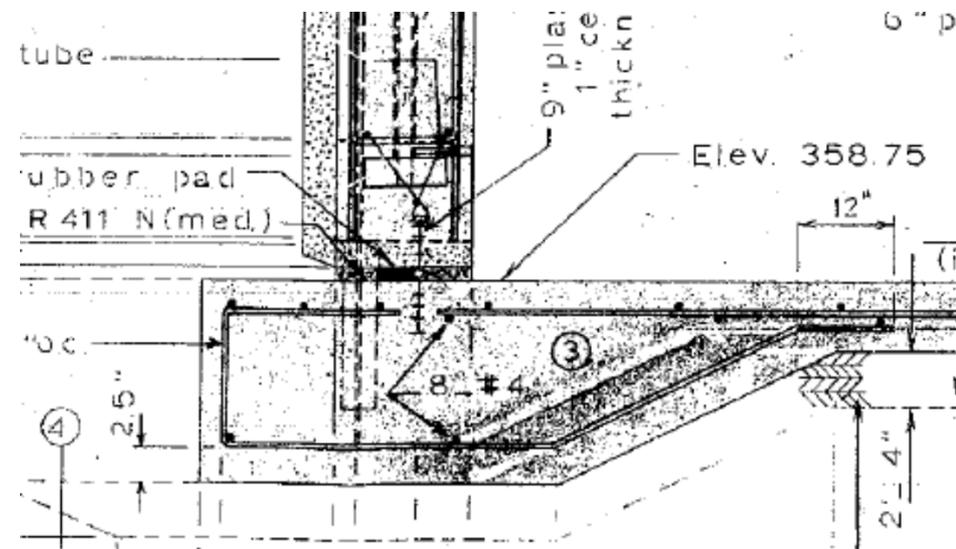
**Floating Reservoir Eval.**  
*During peak demand*



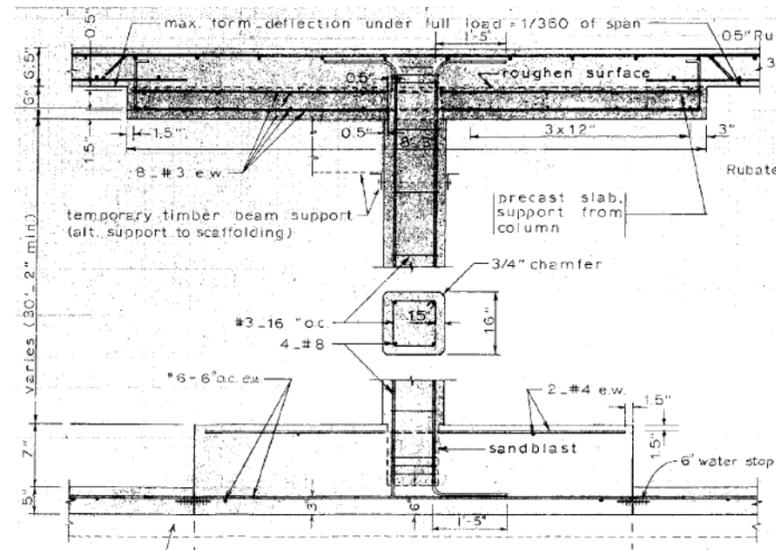
**Diving Inspection**  
*Anytime*

# As-Built Verification & Condition Assessment

*Joints not depicted in the record drawings*



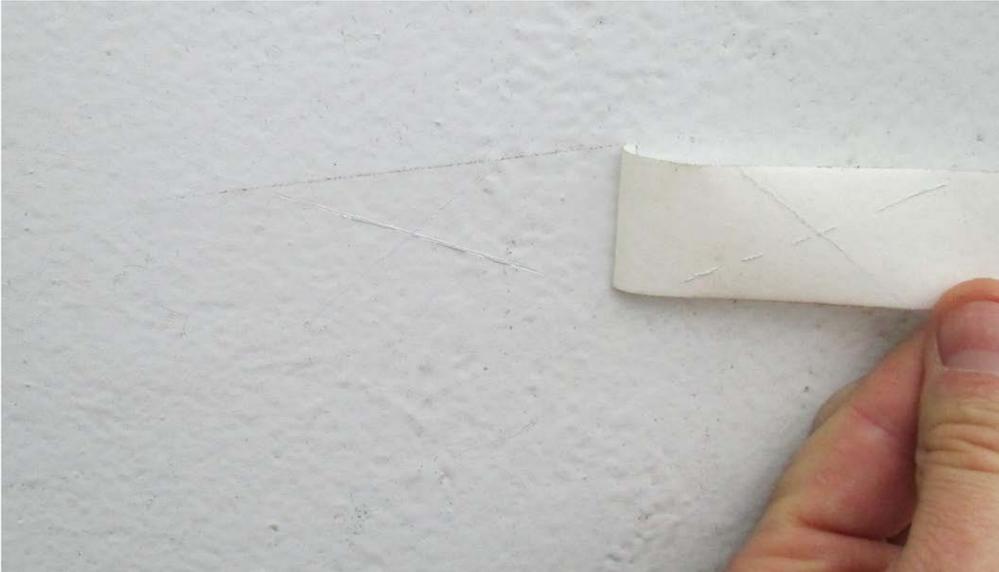
*Construction that varies from the record drawings*



*Deterioration resulting in changes to assumed condition*



# Inspection – Non-Destructive Testing



Data plates, adhesion testing, thickness testing, and sounding

# Inspection – Destructive or Advanced Testing

## Destructive or Advance Testing

1. Ground Penetrating Radar
2. Coupon Testing for Shells or Rebar
3. Strand-wrap Evaluation

### Tensile Testing: Per ASTM A370

Sample ID	1	2	3	4	ASTM A36
Width, in.	0.498	0.496	0.497	0.497	
Thickness, in.	0.541	0.391	0.242	0.261	
Area, in <sup>2</sup>	0.2694	0.1939	0.1203	0.1297	
Yield, lbs	9,707	6,785	4,791	4,990	
Yield, ksi (0.02% offset)	36.0	35.0*	39.8	38.5	36.0 min
Load, lbs	16,741	11,148	7,262	7,347	
Tensile strength, ksi	62.1	57.5*	60.4	56.6**	58.0-80.0
Elongation in 2 in, %	39.0	40.5	33.0	37.0	23.0 min

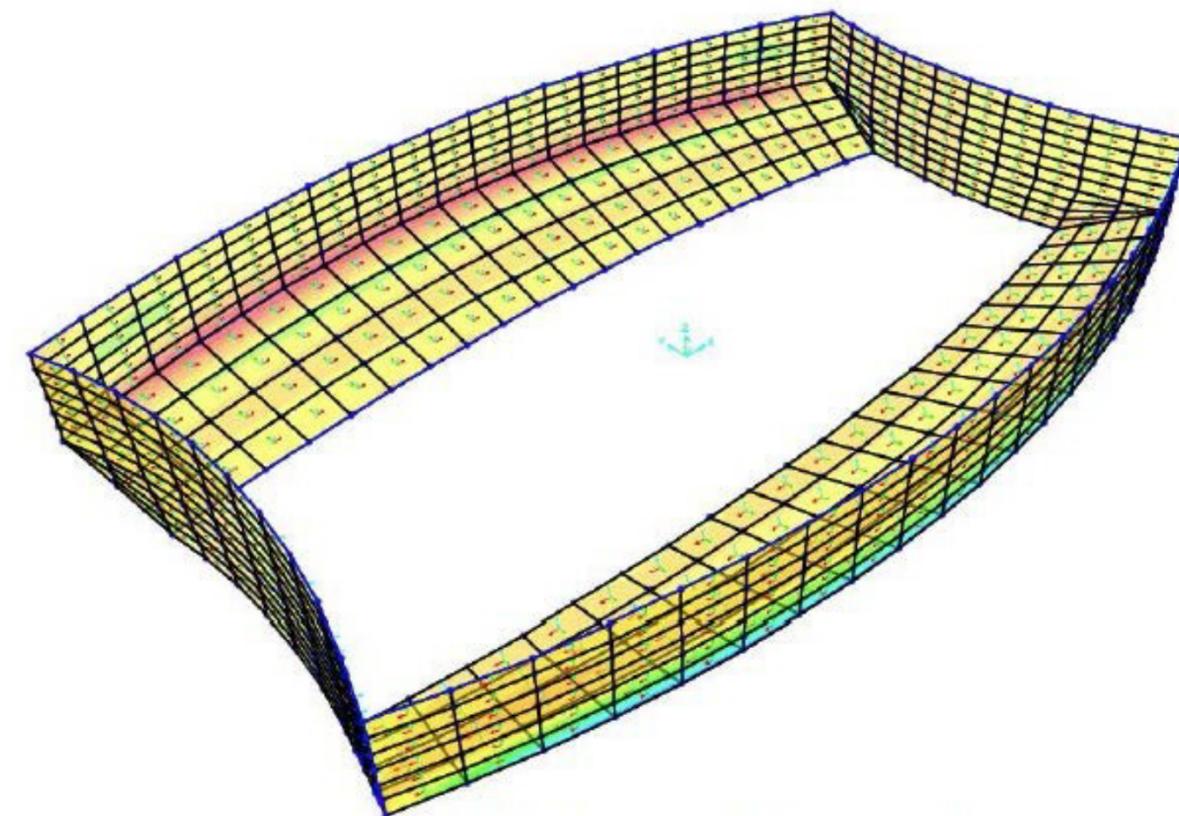
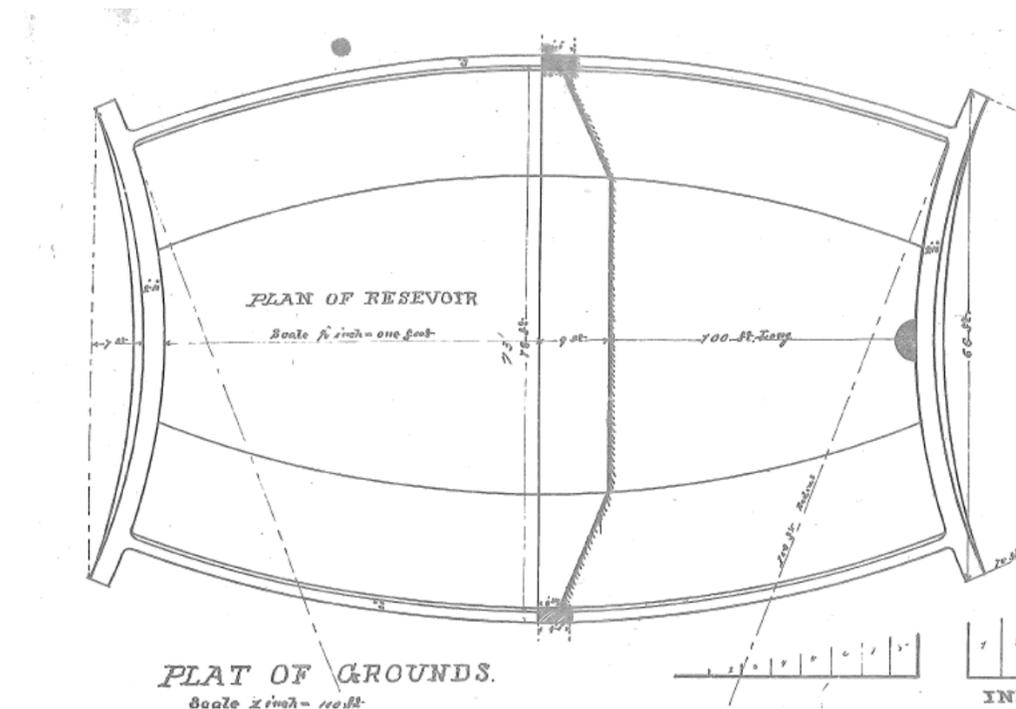
\*Sample 2 is below the minimum yield strength and below the required tensile strength range for ASTM A36 material.

\*\*Sample 4 is below the required tensile strength range for ASTM A36 material.



# Structural Analysis

- ✓ Evaluation per Current Codes
  - 2018 International Building Code (IBC)
  - ASCE 7-16 Minimum Design Loads for Buildings and Other Structure
  - Relevant Standards and References
  - Impending coded and standard (i.e., the forthcoming ASCE 7-22 adoption)
- ✓ Assessment based on in-situ conditions and documentation
- ✓ Seismic resiliency analysis for anticipated earthquake events



Reservoir Shell – Columns, Roof, Buttresses not shown



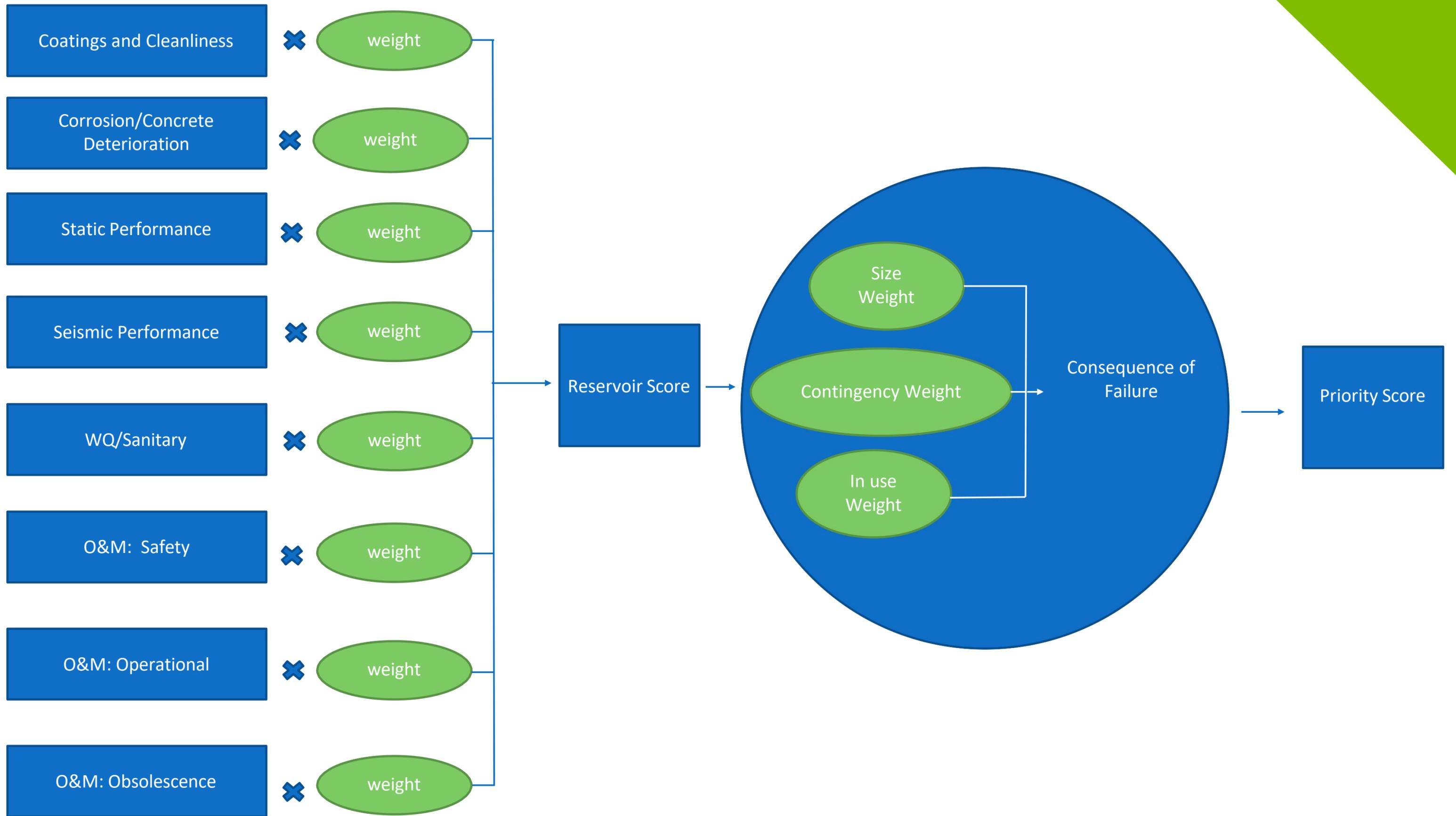
# **What to Do with All that Data?**

# Inspection Results

System/Structure	Category	Coatings and Cleanliness	Corrosion/Concrete Deterioration	Structural Performance		WQ/Sanitary	Operation and Maintenance		
				Static	Seismic		Safety	Operational	Obsolescence
Site/Security	Fences and Gate(s)	0	0	0	0	0	0	4	0
	Vegetation Separation	0	0	0	0	0	0	2	0
	Site Drainage	0	0	0	0	0	0	2	0
Walls	Exterior Walls	3	4	3	3	3	0	5	0
	Interior Walls	5	5	3	3	4	0	5	0
Floor/Foundation	Exterior Floor/Foundation	4	5	3	2	5	0	5	0
	Interior Floor	4	5	3	2	4	0	5	0
	Anchors (Steel) / Seismic Cables (PS)	0	4	5	2	0	0	0	0
Roof	Exterior Roof	3	4	5	2	5	0	4	0
	Interior Roof	5	5	5	2	0	0	0	0
	Columns	5	4	5	2	0	0	0	0
Appurtenances	Exterior Ladders/Fall Protection	5	4	0	0	0	3	3	0
	Interior Ladders/Fall Protection	0	0	0	0	0	0	0	0
	Access Hatches	3	4	0	0	2	0	2	0
	Railings and Roof Fall Protection	0	0	0	0	0	1	0	0
	Vents and Screens	5	4	0	0	2	0	1	0
	Balconies/Landings/Grating	0	0	0	0	0	0	0	0
Piping/Valving	Inlet Piping	0	4	0	2	5	0	5	0
	Outlet Piping	0	4	0	2	5	0	5	0
	Drain Piping	0	4	0	2	3	0	2	0
	Overflow Piping	0	4	0	0	4	0	2	0
	Washdown Piping	0	0	0	0	0	0	1	0
	Attached Valve Vault Structure	0	0	0	0	0	0	0	0
	Control Valving	5	5	0	0	5	0	5	5
	Isolation Valving	5	5	0	0	5	0	5	5
Misc.	Cathodic Protection System	0	0	0	0	0	0	3	3
	Level Sensors	0	0	0	0	0	0	5	0
	Hydraulic Mixing System	0	0	0	0	5	0	5	0

# Condition Assessments

Criteria	5	4	3	2	1			
Coatings and Cleanliness Score								
Corrosion/Concrete Deterioration Score								
Structural Performance Score						GOOD	Fair	POOR
Water Quality / Sanitary Score								
Safety Score								
Operational Score								
Obsolescence Score								



# Condition Assessments

Category Weight	
Coatings and Cleanliness	10
Corrosion/ Concrete Deterioration	10
Static Structural Performance	15
Seismic Structural Performance	25
WQ/ Sanitary	15
Safety	10
Operational	10
Obsolescence	5
	100

Summary Table	
Categorical Scores	
Coatings and Cleanliness	3.9
Corrosion/ Concrete Deterioration	3.1
Structural Performance - Static	2.0
Structural Performance - Seismic	1.6
WQ/ Sanitary	1.8
O&M - Safety	2.3
O&M - Operations	2.5
O&M - Obsolescence	2.8
Selected System Scores	
Exterior Coatings	3.5
Interior Coatings	0.75
Exterior Corrosion	3
Interior Corrosion	1

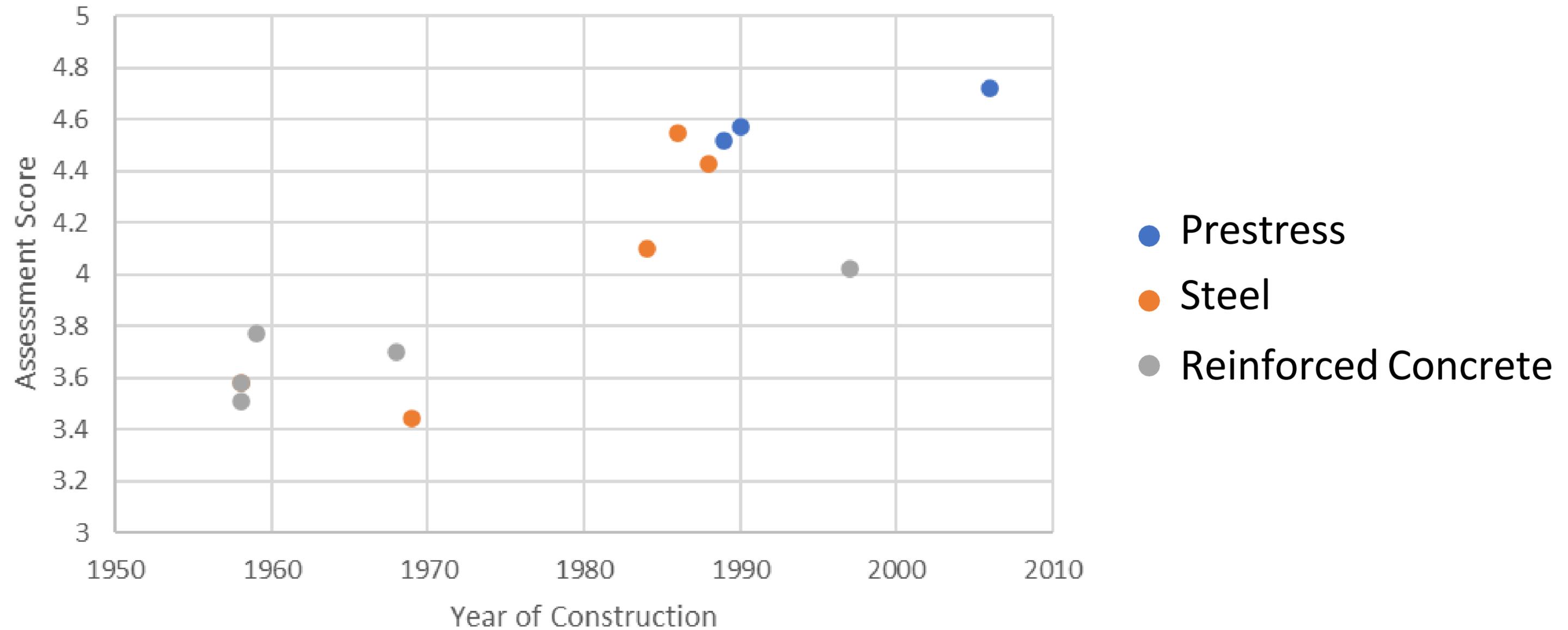
Overall System Score

2.30

# Condition Assessments – Example Results

System/Structure	Category	Coatings and Cleanliness	Corrosion/Concrete Deterioration	Structural Performance		WQ/Sanitary	Operation and Maintenance			Overall					
				Static	Seismic		Safety	Operational	Obsolescence	Total Weights	Weighted Score	Conseq of Failure	Sum CoF	Mean CoF	System Score
Site/Security	Fences and Gate(s)	0	0	0	0	0	0	5	0	10	5.00	2	5	2.5	4.4
	Vegetation Separation	0	0	0	0	0	0	0	0	0	0.00	1			
	Site Drainage	0	0	0	0	0	0	4	0	10	4.00	3			
Walls	Exterior Walls	0	4	3	3		0	0	0	50	3.20	5	10	5.0	3.1
	Interior Walls	0	4	3	3	2	0	0	0	65	2.92	5			
Floor/Foundation	Exterior Floor/Foundation	0	4	3	2	0	0	0	0	50	2.70	5	10	3.3	2.9
	Interior Floor/Foundation	0	4	3	2	0	0	0	0	50	2.70	2			
	Anchoring System	0	4	5	2	0	0	0	0	50	3.30	3			
Roof	Exterior Roof	0	4	5	2	0	0	0	0	50	3.30	5	15	5.0	3.3
	Interior Roof	0	4	5	2	0	0	0	0	50	3.30	5			
	Columns	0	4	5	2	0	0	0	0	50	3.30	5			
Appurtenances	Exterior Ladders/Fall Protection	0	4	0	0	0	3	0	0	20	3.50	2	11	2.2	3.0
	Interior Ladders/Fall Protection	0	0	0	0	0	1	1	0	20	1.00	2			
	Access Hatches	0	4	0	0	0	1	0	0	20	2.50	2			
	Railings	0	0	0	0	0	1	0	0	10	1.00	1			
	Vents and Screens	0	4	0	0	0	0	5	0	20	4.50	4			
	Balconies/Landings/Grating	0	0	0	0	0	0	0	0	0	0.00	1			
Piping/Valving	Inlet Piping	0	4	0	0	5	0	0	0	25	4.60	4	19	2.7	3.9
	Outlet Piping	0	4	0	0	5	0	0	0	25	4.60	5			
	Drain Piping	0	4	0	0	0	0	2	0	20	3.00	2			
	Overflow Piping	0	4	0	0	0	0	2	0	20	3.00	4			
	Washdown Piping	0	0	0	0	0	0	1	0	10	1.00	1			
	Flexible Connections	0	0	0	0	0	0	0	0	0	0.00	2			
	Attached Valve Vault Structure	0	0	0	0	5	0	4	4	30	4.50	2			
	Control Valving	0	0	0	0	5	0	4	4	30	4.50	1			
	Isolation Valving	0	0	0	0	0	0	0	0	0	0.00	1			
Piping/Valving	Cathodic Protection System	0	0	0	0	0	0	3	2	15	2.67	3	8	2.7	4.1
	Level Sensors	0	0	0	0	0	0	5	0	10	5.00	3			
	Hydraulic Mixing System	0	0	0	0	5	0	0	0	15	5.00	2			
<b>Categorical Score</b>		0.0	4.0	4.0	2.3	4.5	1.5	3.3	3.3						
										W/ CoF	<b>Overall System Score</b>				
											<b>3.44</b>				

# Aggregated Results



# Key Takeaways

- ✓ Comprehensive evaluation of storage assets works best with a methodical, consistent approach
- ✓ Performing evaluations provides a foundation for project prioritization





Q&A



**Thank you!**