Structural Health Monitoring for USACE Operations and Asset Management Support

ERDC
Engineer Research and Development Center

Presentation at the TRB CMTS Conference

Washington, DC

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USACE-ERDC

21 June 2016

US Army Corps of Engineers®

USACE – Lots of Stuff!

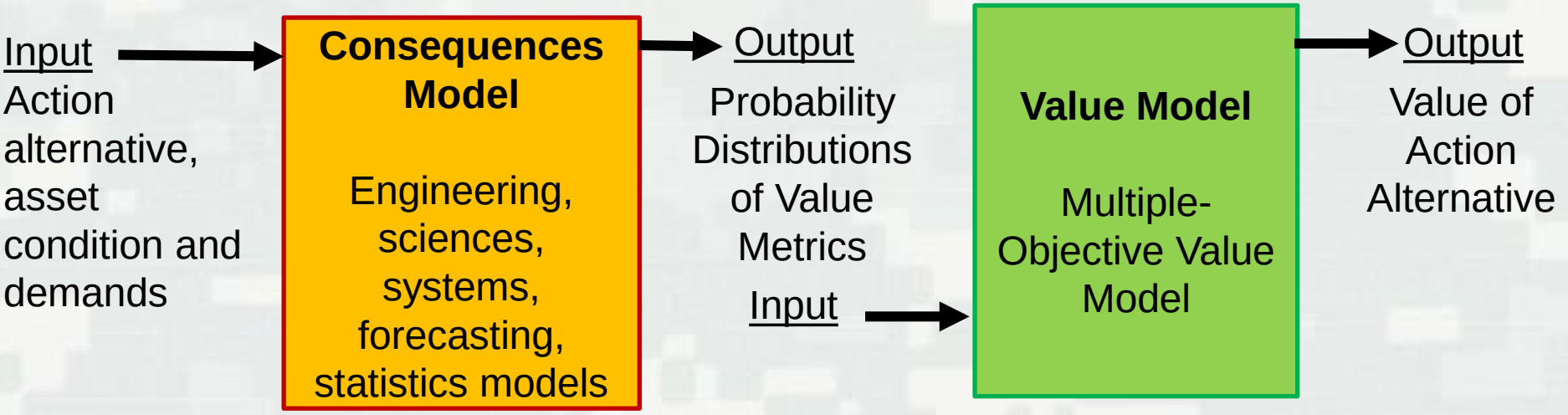
- $250B infrastructure replacement value
- 12,000+ miles of navigable inland waterways
- 926 commercial harbors
- 191 locks
- 353 hydroelectric power generation units
- 694 dams
- 14,700 miles of levees
- Over 800 bridges
- Buildings, roads, recreation sites, environmental projects, etc…

Operations and Asset Management

- We need to make optimal decisions in order to **Operate** and **Invest** in our infrastructure assets
- This requires being able to answer questions like:
  - Whether to take action
  - How to take action
  - Value of taking action
  - When to take action
  - Understanding future effects of action

Enterprise Value Model

- USACE currently exploring a transparent value model to make value-informed decisions



Consequences Model

- Take in current asset condition (sensors/inspections) and possible repair/maintenance alternatives
- Degradation models
- Forecast future loading demands (climate change, economic change)
- Predict future condition and uncertainty
- Compute value metrics (property/persons at risk, expected commercial value shipped, etc.) as probabilistic distributions

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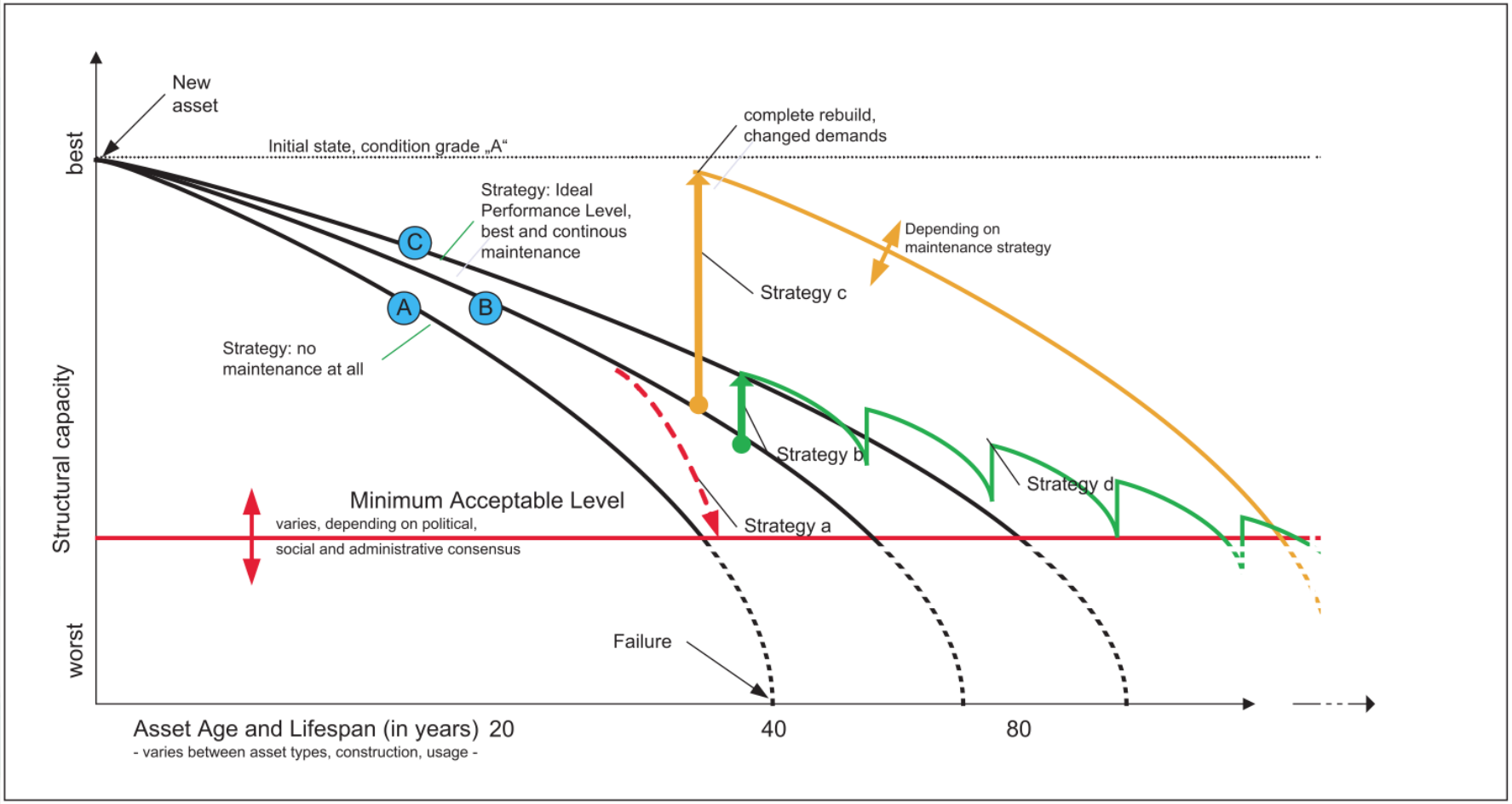
Consequences Model



Why Structural Health Monitoring?

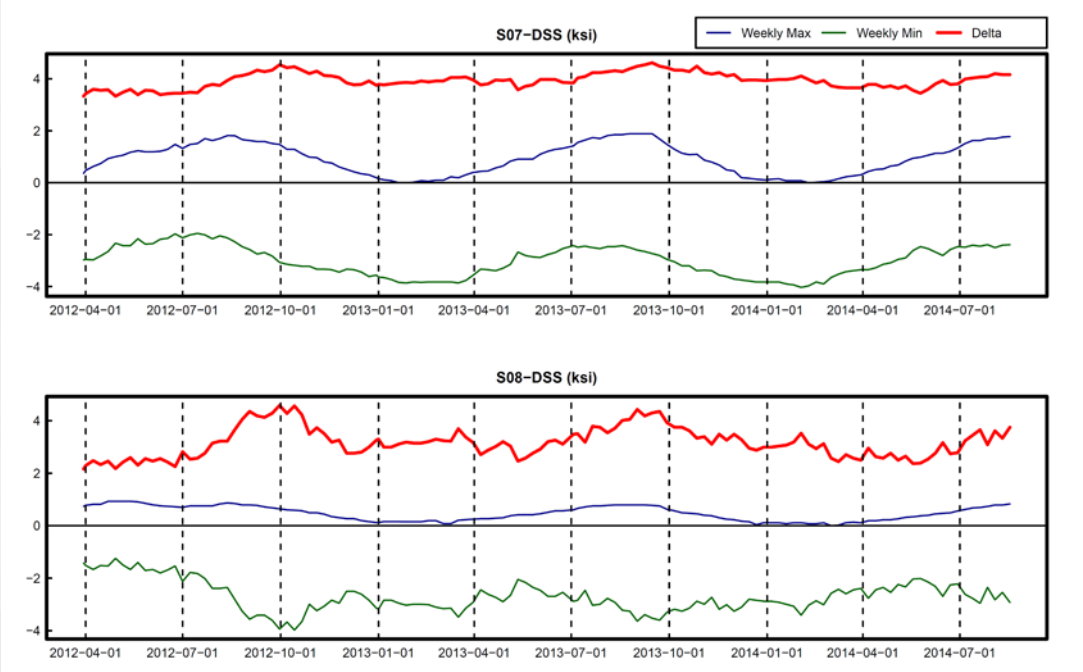
- SHM – Science of making accurate condition assessments about the current ability of a structural component or system to perform its intended design function(s), based on:
  - Sensor/inspection data
  - Multi-physics (structural/thermal/hydraulic) models
  - Statistical models
- Damage Prognosis extends by considering probabilistic future loading and failure mode models to forecast remaining useful life or similar performance variables

Current USACE SHM Work

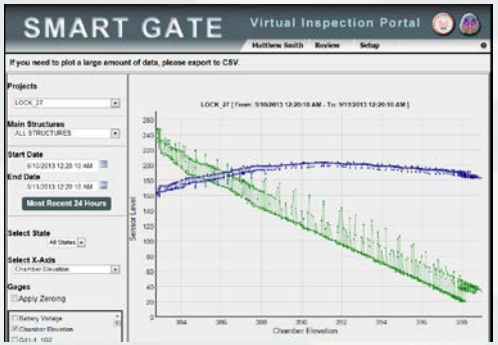
- Operational information for navigation locks
  - Barge impact detection (ARMA time-series models and statistical process control)
  - Lock gate debris impediment (Gaussian process regression, GPR)
  - Degrading boundary conditions (Cointegration and principal component analysis, GPR of finite element, strain and thermal sensors)
  - Fatigue crack propagation and remaining life of steel gates
  - Friction in moving parts
- Failure-mode specific rapid inspection methods for levees with uncertainty quantification
- Uncertainty quantification for bridge inspection procedures
- Concrete degradation models
- Alternative sensor telemetry
- Non-destructive evaluation techniques (ultrasonic, impedence, etc.)

Early SMART Gate 1.0

- 5 Lock Projects
  - Greenup
  - The Dalles
  - Bonneville
  - Meldahl
  - Lock 27 (St. Louis)



- Engineering Focus
- Instrumentation Monitoring
- Manual Alarms
- Web-Portal: http://smartgate.erdc.dren.mil
- NWP using this to help decide not to dewater Bonneville in FY15



Lessons Learned

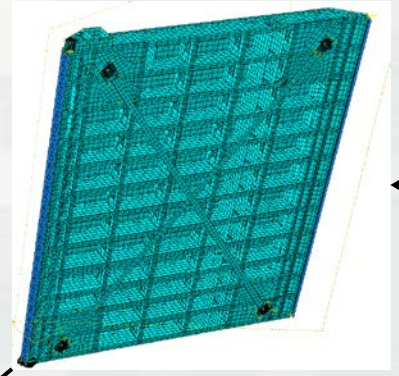
Structural Monitoring and Analysis in Real-Time (SMART)

Version 1.0	Version 2.0
Many Sensors (>200)	Few Sensors (<120)
No Detection Targets	Carefully Selected Targets
Very Expensive	Cheaper
No Automated Decision Support	Automated Event Detection using FEM
Easy Data Access and Plots via Website	Same Web Access with Plotting + Warning Traffic Lights
Manual Alarms (email & text)	Auto and Manual Alarms (email & text)
No Elec/Mechancial Sensors	Incorporated Elec/Mech. Sensors

SMART Gate 2.0

Validation Data

Sensors at Lock

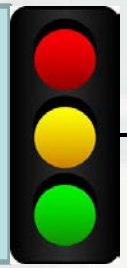


Numerical Models

Surrogate Model

Detection Targets
(Verified with Field Needs)
- Barge Impact
- Quoin/Wall Degradation
- Dragging Debris

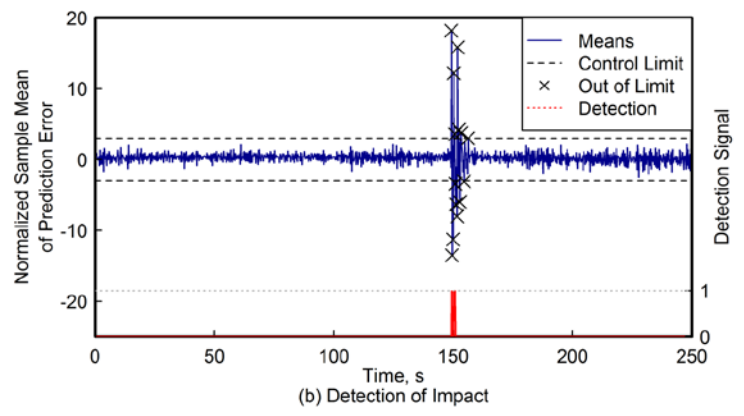
Decision Support
-Warning Lights
-Data Archival/Retrieval
-Email/Text Alerting

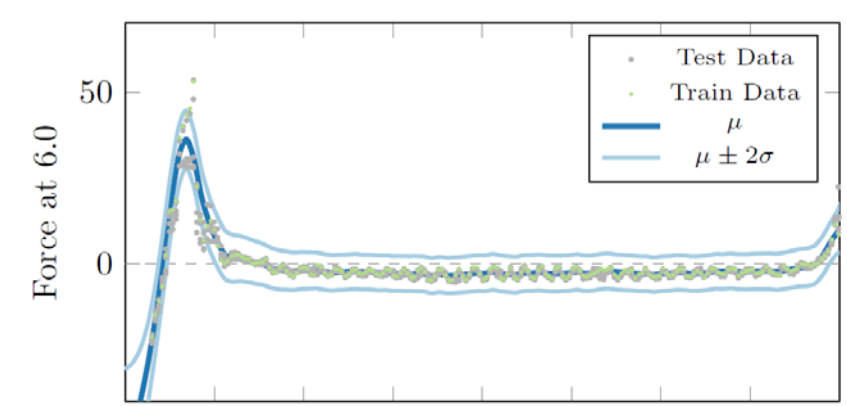


Reachback Capability

SMART Gate 2.0

- Detection of Barge Impact into Recessed Gates
- Single accelerometer per gate leaf
- Accelerometer time series models with statistical process control
- False-positive control





- Detection of trapped/dragging debris
- 3 sensors: Gate position, water level, strut force
- Gaussian process regression

Trunnion Friction Detection

- Low-cost detection of trunnion friction
- Identifies when trunnions need maintenance/greasing
- Based on simple structural models

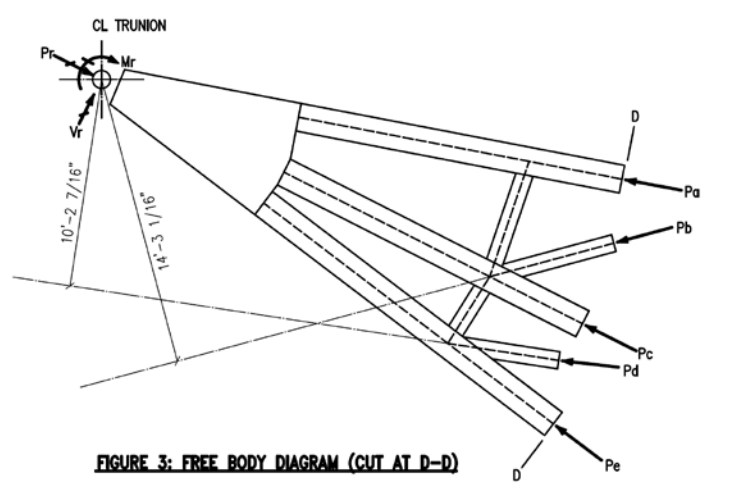
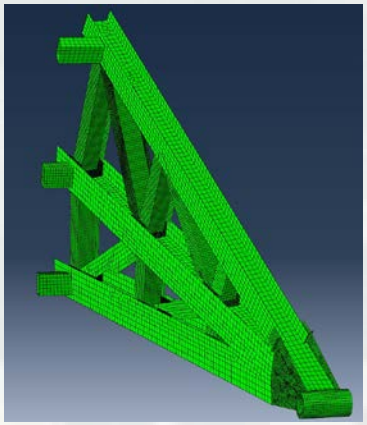
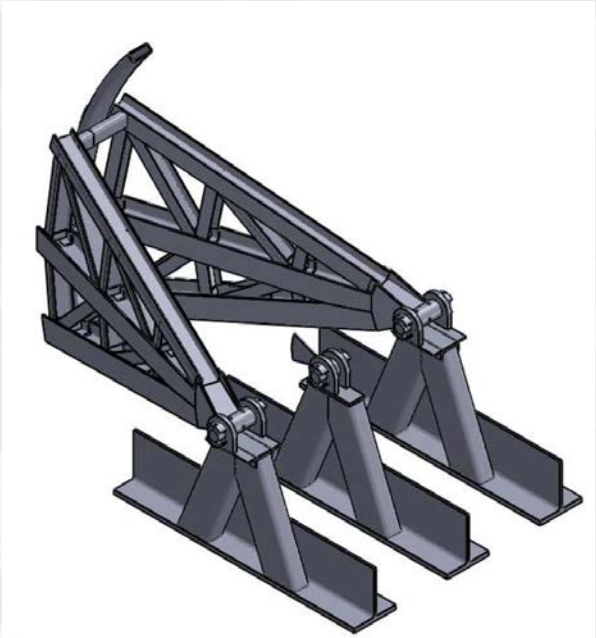


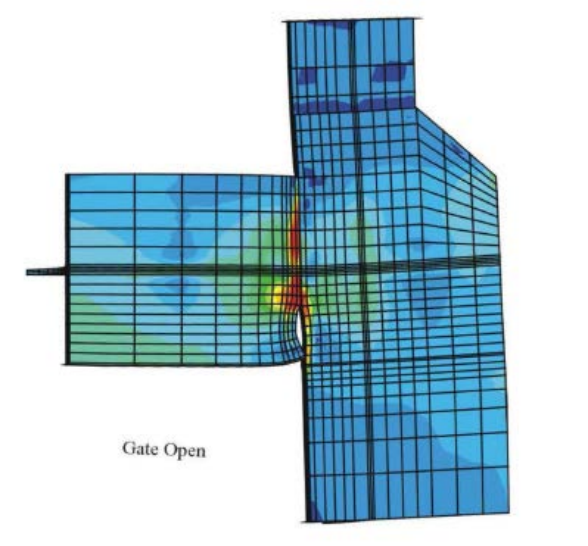
FIGURE 3: FREE BODY DIAGRAM (CUT AT D-D)



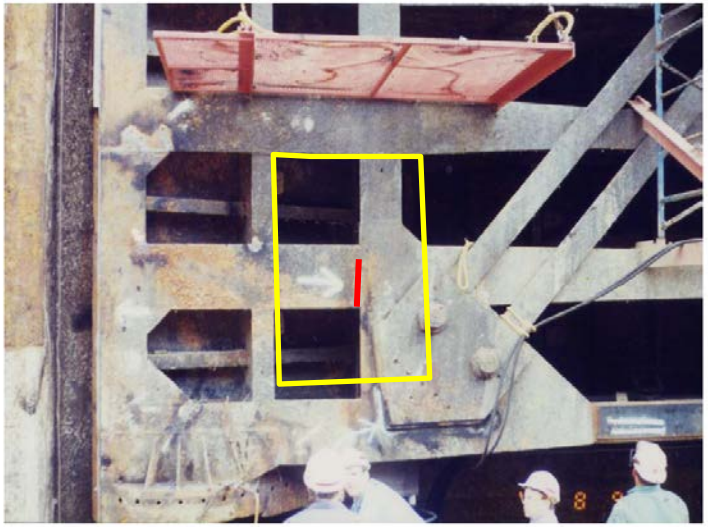


Fatigue Life of Hydraulic Steel Structures

- Gage-calibrated finite element models to predict remaining life due to fatigue
- Can be used to determine best repair strategy



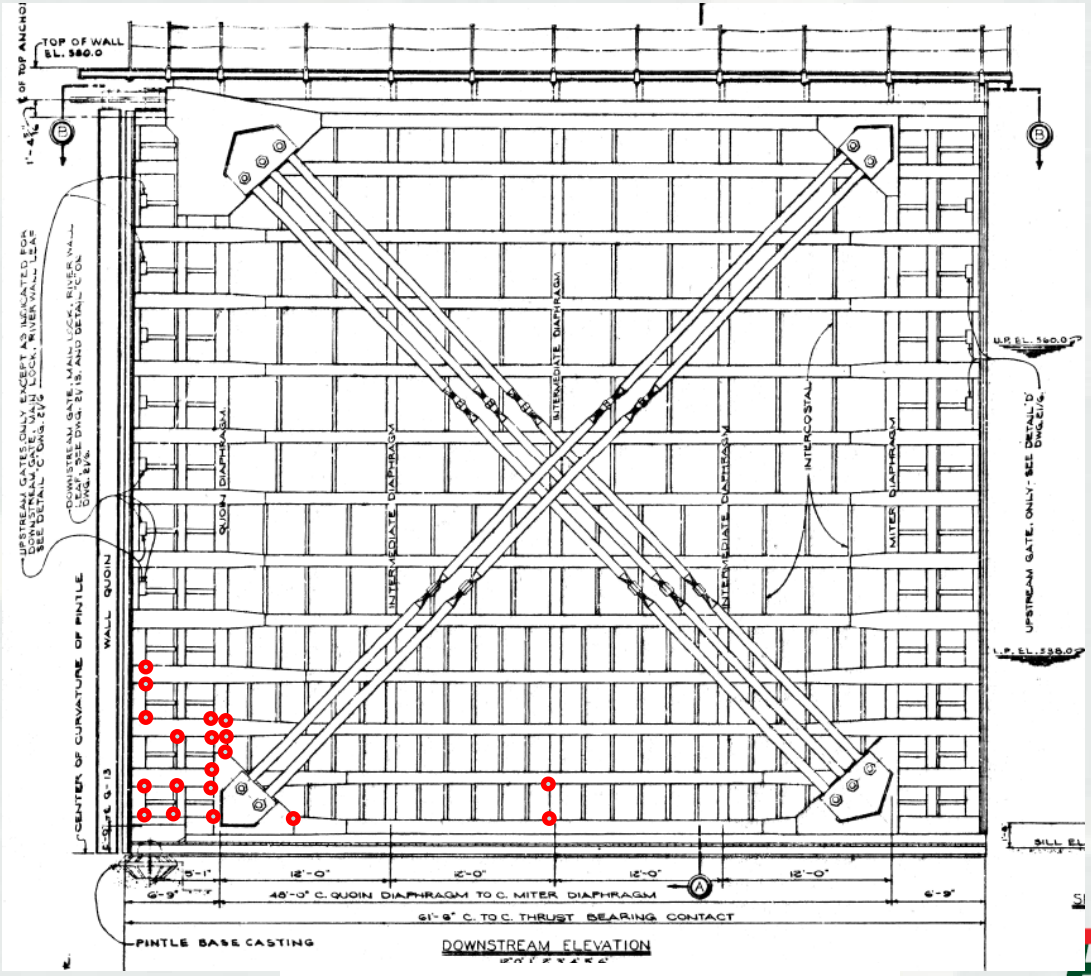
SHM-Based Prediction
(underwater location)



Actual Cracking Found
(Markland, not recent)

Fatigue Life of Hydraulic Steel Structures

- May inform of FUTURE condition



EXPECTED CRACKING

Summary

- Consequence models are probabilistic and need quality input to be predictive
- Combined human inspections and sensing technology provides best potential for quality data
- Sensors/inspections/models/statistics can be combined into models which inform of:
  - Operational issues
  - Conditions leading to catastrophic failures
  - Remaining life
  - Performance metrics (including risk)
  - Framework for comparing repair/maintenance alternatives