WJE

Beyond the Routine (Inspection)

Wiss, Janney, Elstner Associates, Inc.

AAPA
ESSENTIAL. RESILIENT. UNITED.
SEAPORTS DELIVER

New Member Webinar

November 14, 2024

Presenters

Jeff West, PhD, PE
Associate Principal
WJE Austin

Jeremiah Fasl, PhD, PE
Associate Principal
WJE Austin

Webinar Outline

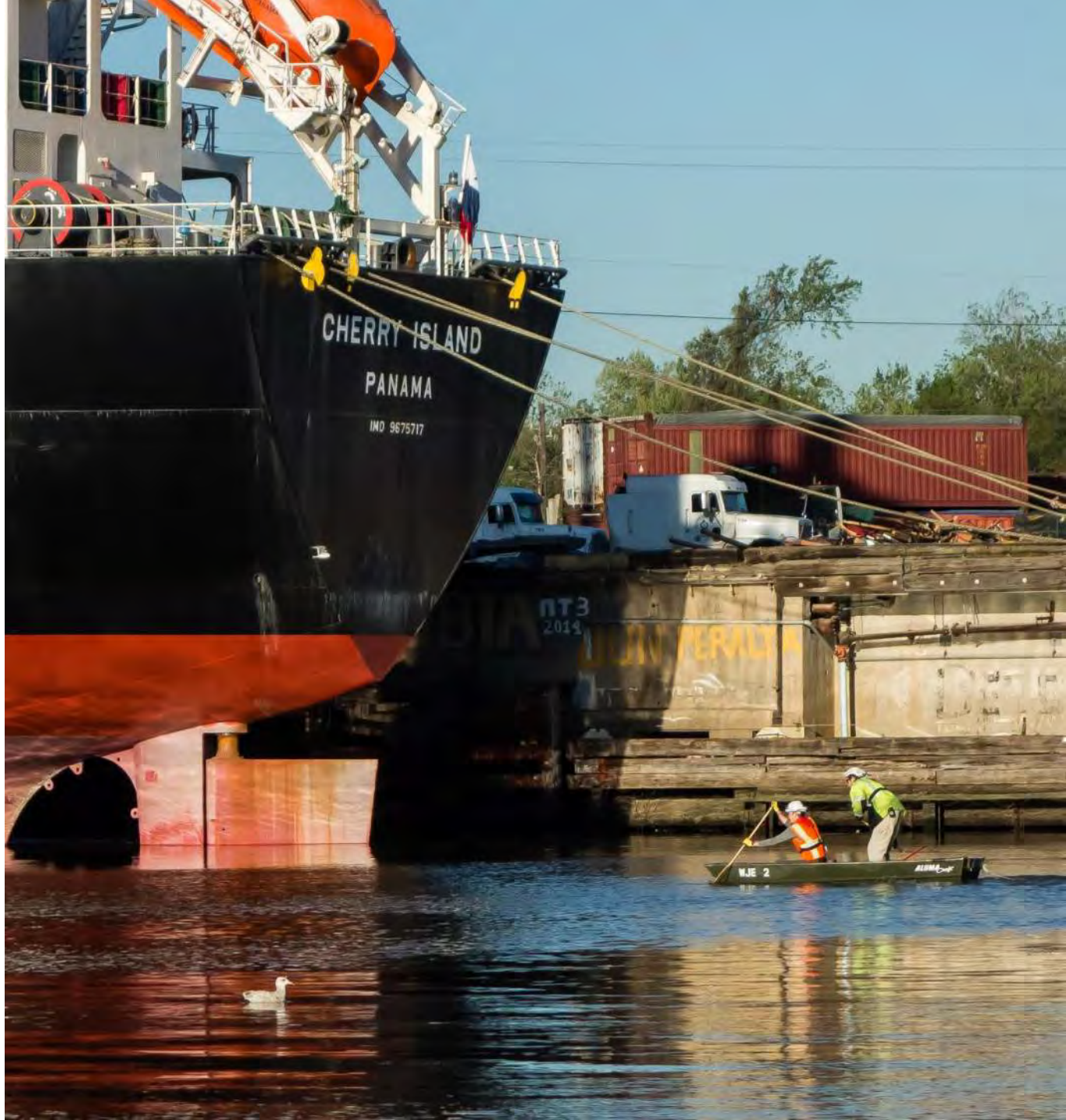
- Who We Are
- Routine Condition Inspection: Key to Asset Management
- Beyond the Routine Inspection
  - In-depth Corrosion Assessment and Service Life Modeling
  - Shiploader Fatigue Evaluation
  - Wharf Substructure Evaluation

Who We Are

Firm Background

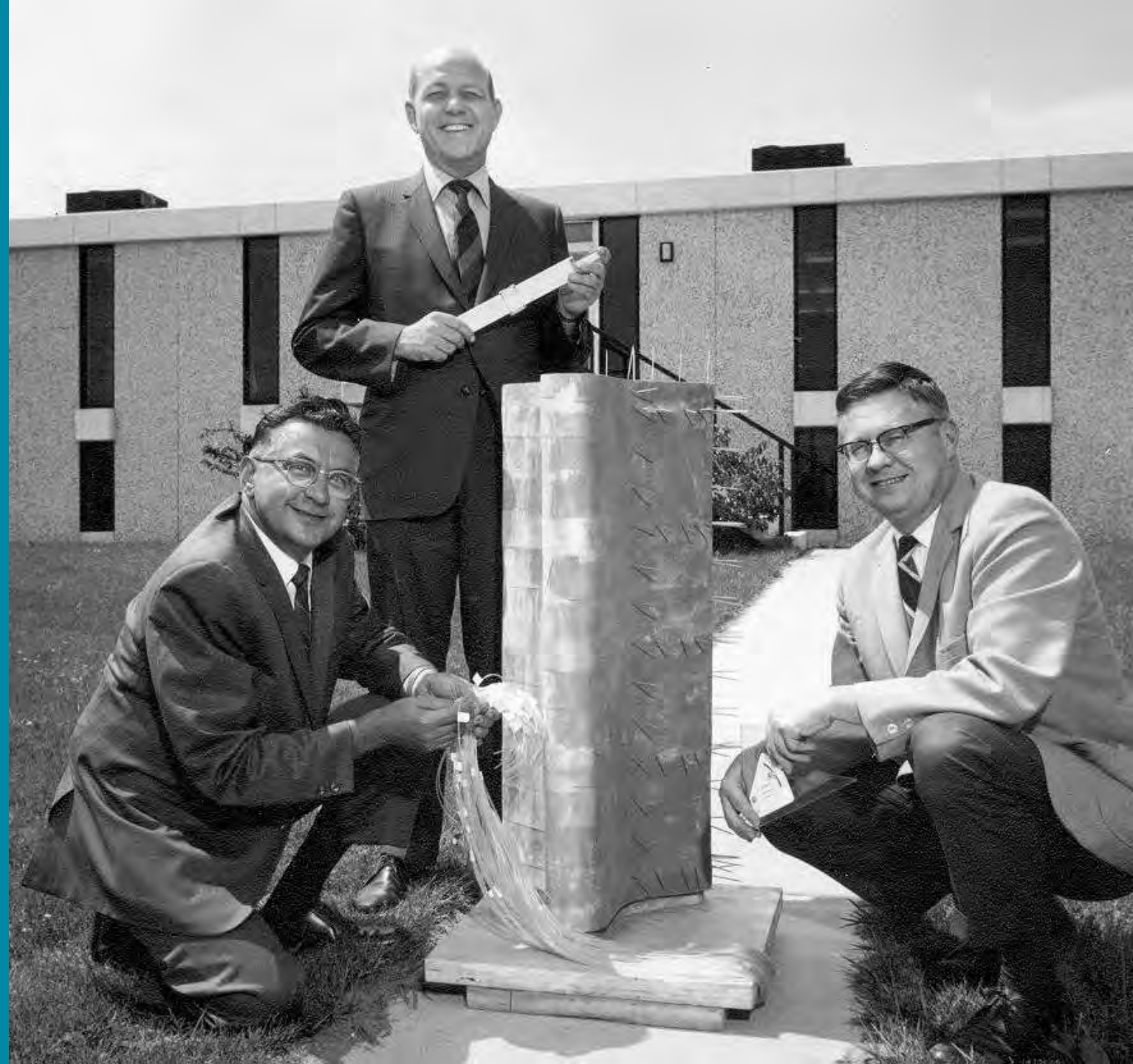
Core Services

Experience

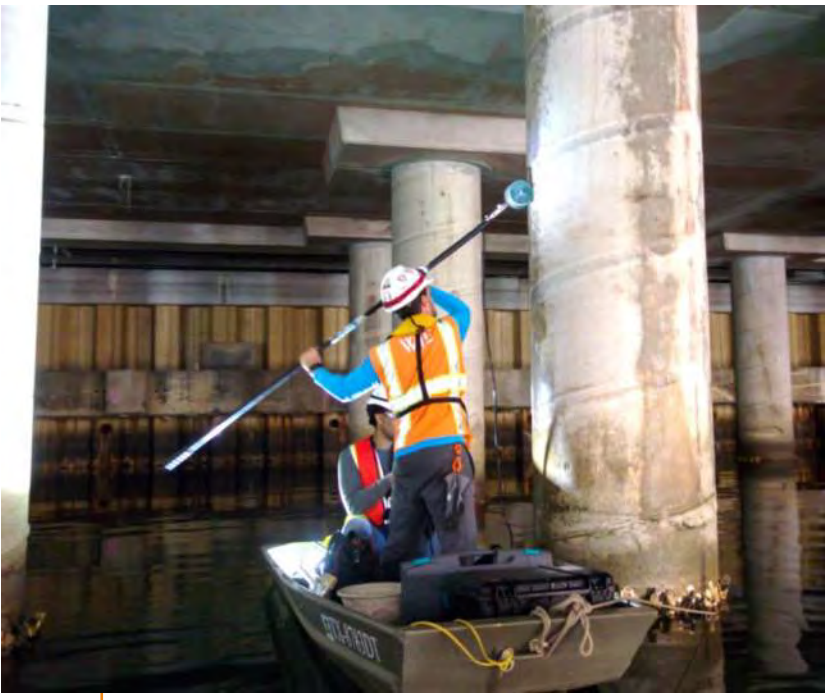


“Ask the Structure”

- Engineers, Architects, and Material Scientists
- Specialize in problem solving for existing infrastructure
  - Investigation, analysis, testing
  - Repair and rehabilitation
- Founded in 1956
- Employee-owned
- 750+ Employees



Expertise & Qualifications

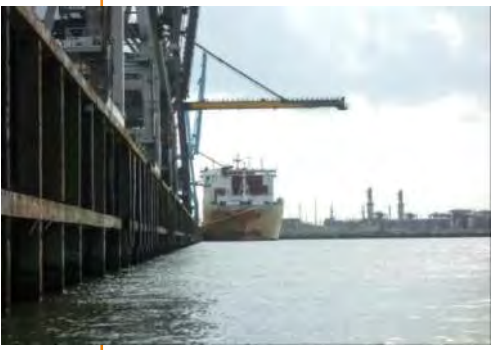


Unmatched experience and expertise in evaluation, repair, and rehabilitation design

7,000

maritime structure assessments

In-house structural, concrete, metallurgy, material science, and chemistry laboratories



1,000

publications on the evaluation, repair, and rehabilitation of concrete structures

Significant government-sponsored research

NCHRP, SHRP, FHWA, PCI, ACI

Core Services

- **Structural Engineering**
  - Condition Assessment: Above Water and Underwater
  - Nondestructive Evaluation
  - Corrosion & Service Life Modeling
  - Load Rating
  - Load Testing & Instrumentation
  - Repair and Rehabilitation Design
    - Damage and deterioration
    - Strengthening or modification
    - Design for service-life (durability)
- **Asset Management**
  - Assessment Program Development
- **Laboratory Materials Evaluation**
  - Concrete Petrography
  - Distress and Failure Analysis
  - Materials Selection and Evaluation
  - QA/QC Testing
- **Geotechnical Engineering**
  - Slope Stability Analysis
  - Deep Foundation Analysis and Design
  - System Identification using Impulse Response

Port Experience

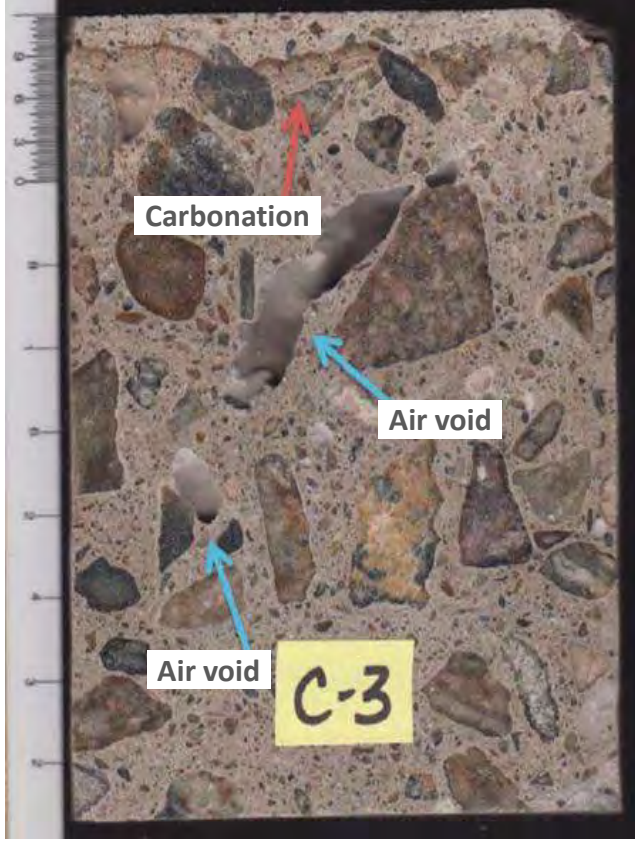
- Port Houston
  - Barbours Cut Terminal
    - Wharves 1, 2, 3, 4, 5 & 6
  - Manchester Terminal
    - Wharf 2
  - Turning Basin Terminal
    - Wharves 1, 2, 9, 12, & 23
  - Woodhouse Terminal
  - FICAP Program Development
  - FICAP Inspections
    - Turning Basin
    - Barbours Cut
    - Bayport
- Port of Corpus Christi
- Port of Port Arthur
- Port of Brownsville
- Port Isabel
- Port of Long Beach
- Port of Los Angeles
- Port of Stockton
- Port Jefferson
- Port Authority of NY & NJ
- Port of Seattle
- Port of Columbia Lyons Ferry Marina
- Port Hueneme
- Port of Baton Rouge

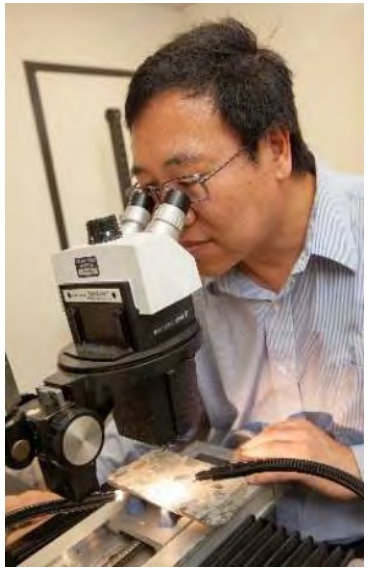
WJE Laboratories

- **Janney Technical Center**
  - Northbrook, IL
  - Structures, Concrete, Petrography, Chemistry, Metallurgy
- **WJE-Austin**
  - Concrete & Petrography
- **WJE-Cleveland**
  - Petrography

Laboratory Services

- Concrete Materials Evaluation
  - Compressive Strength
  - Composition and quality
  - Distress Mechanisms (ASR, sulfate attack, etc.)
  - Chloride Analysis
  - Carbonation
- Steel and other Metals
  - Strength Testing
  - Weld failure and fracture analysis
- Coatings
  - Materials selection
  - Failure analysis





Routine Condition Inspection:
Key to Asset Management

Inspections and Condition Assessments to Support Asset Management

Maritime Structure Asset Management

- Strategic Asset Management (SAM) is an enterprise level **decision support system**

- Answers questions:
  - What is the condition of the asset?
  - Does it need repair, and if so, when?
  - Should we replace it instead of repair it?
  - Is it okay if we “do nothing” (for now)?

Strategic Asset Management:
Decision Support System → Prioritization of Capital Expenditures

Asset Condition Assessment

Asset Operational Performance

Rehabilitation or Modification Recommendations and Costs

Data Driven Process

Asset Structural and Functional Characteristics

Prioritization of Expenditures

Asset Value and Revenue

RISK

Objectives of Condition Assessment for Asset Management

➔ Provide input data for prioritization of capital expenditures

- Establish asset condition at a point in time to:
  - Define value
  - Define baseline conditions for legal purposes (e.g., change of ownership, new lease, etc.)
  - Enable monitoring of ongoing deterioration or damage over time when inspections are conducted at regular intervals
- Identify conditions that require maintenance, repair, or replacement
- Identify conditions that may compromise facility operations, or may lead to property or environmental damage

Primary approach to collecting essential "input data" is a Routine Inspection Program

Routine Inspection Program

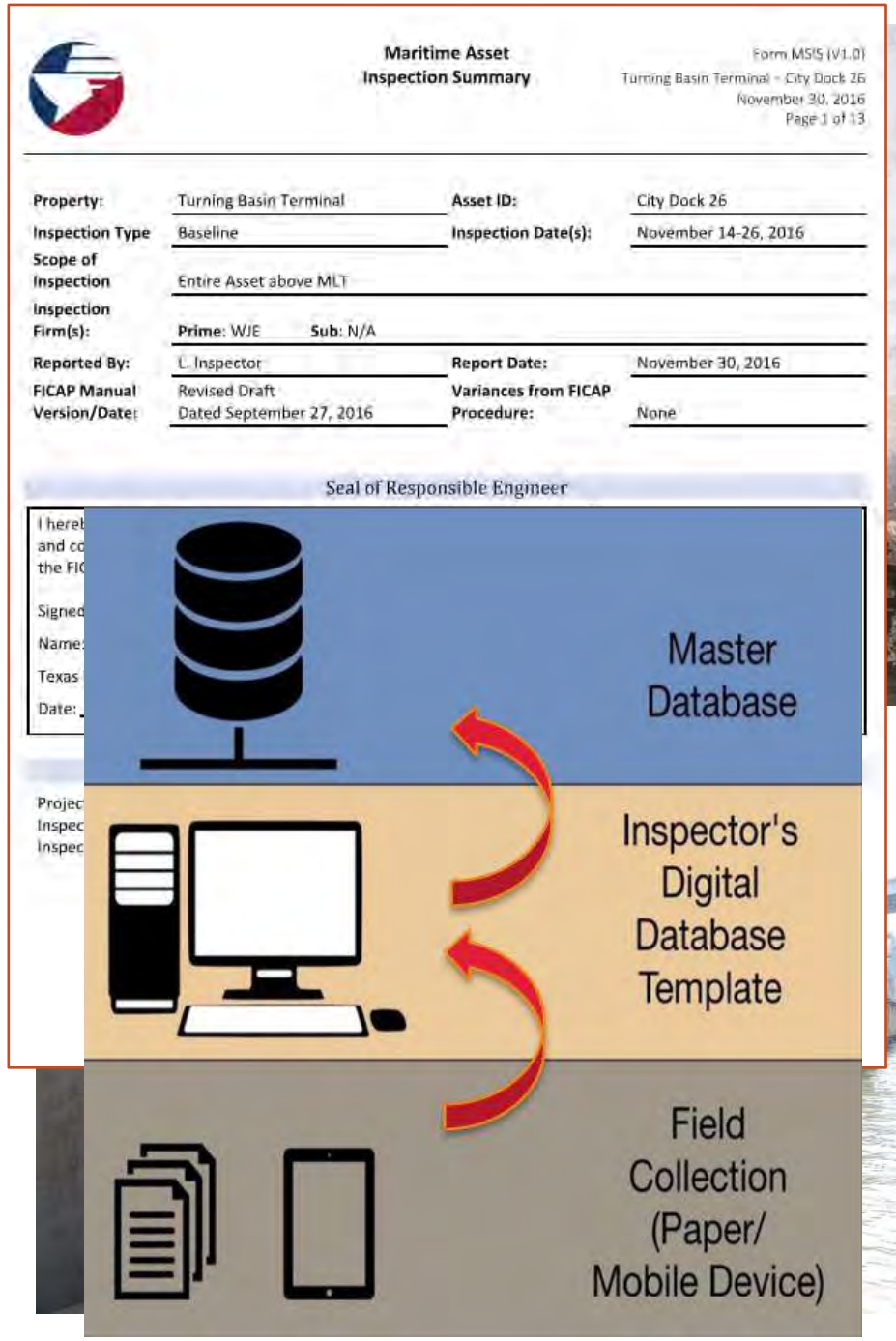
Port Houston:

Maritime Facilities Inspection and Condition Assessment Program (FICAP)

- Example of condition assessment program for asset management
- Part of overall Port Houston Strategic Asset Management Strategy
- **FICAP Marine Structures:** Structural and functional components
- **FICAP Corrosion:** Corrosion protection systems on marine structures

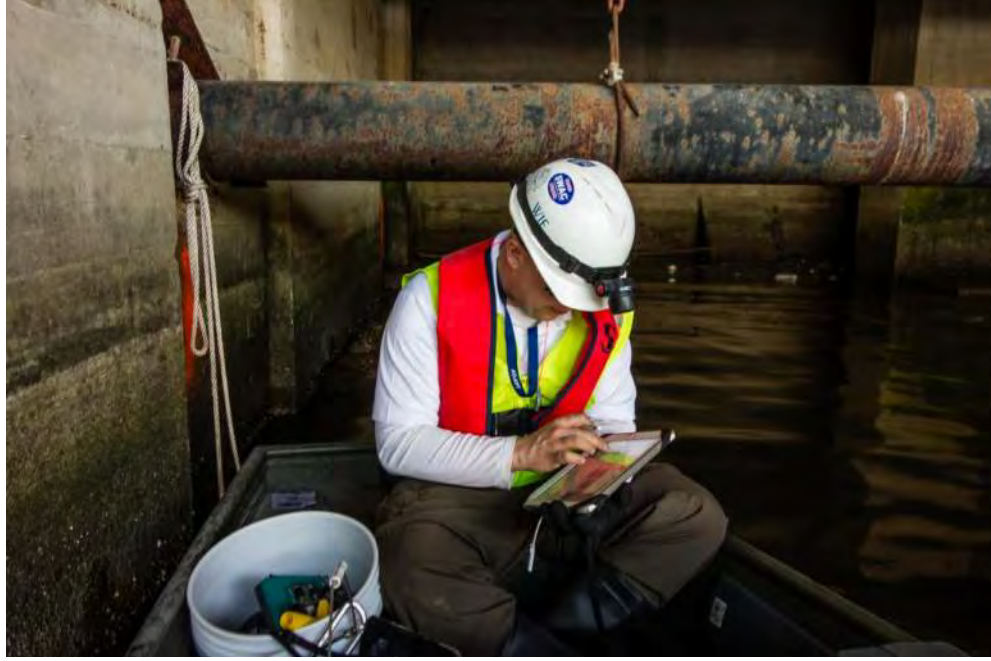
Inspection Program – Key Features

- Overall **Asset** condition ratings
- Element-based inspection approach tailored to maritime structures
- Different Inspection Types:
  - Baseline, Routine, Special
- Standardized data collection
- Standardized documentation
- Database Integration: MS SQL and GIS
- Inspection Team qualifications



Standardized Routine Inspection Condition Data

- Ranking of asset condition within inventory
- Prioritization of capital expenditures
  - Maintenance and Repairs
  - Future replacement or modifications
- Evaluation of system and material performance over time
  - Effectiveness of corrosion protection measures
  - Performance of replaceable systems and elements: coating systems, wearing surfaces, fender systems, and ancillary components
  - Supplements “value analysis” of protection measures



Sometimes a Routine Inspection is not Enough…

- Routine inspection is typically visual
  - Provides an overall assessment of current condition of asset
  - Identifies obvious conditions that require maintenance, repair, or **further investigation**
- **Special or in-depth investigation** may be required to answer:
  - Is it safe now?
  - Can we keep using it?
  - How long will it last (before major repair is required)?
  - How do we fix it?
  - How do we prevent this in the future?

Beyond the Routine:
In-Depth Corrosion Assessment

Condition Evaluation and Remaining Service Life Modeling for Concrete Structures in Saltwater Environments

In-Depth Corrosion Assessment: Common Objective

How long until this…

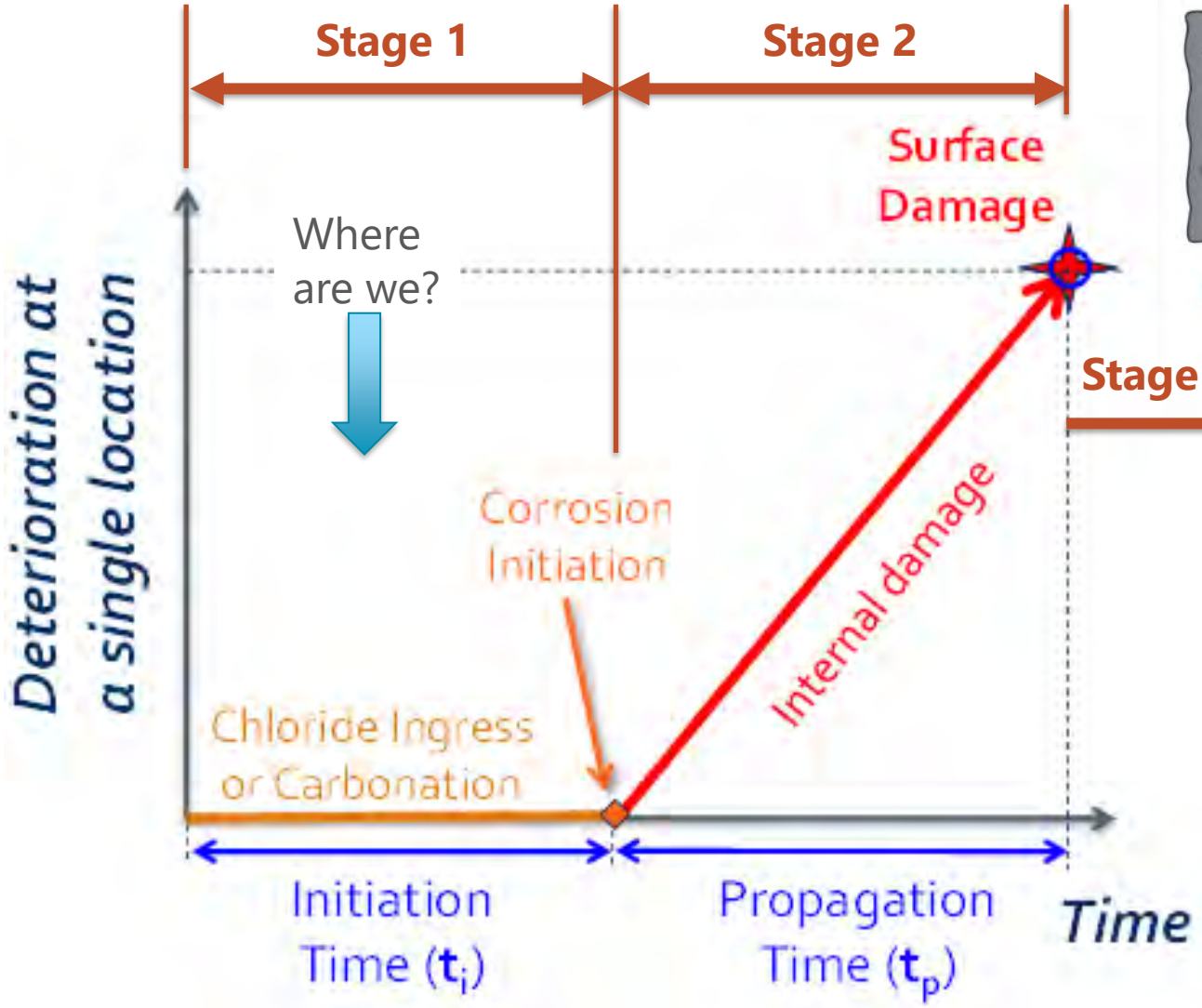
In-Depth Corrosion Assessment: Common Objective

…becomes this?

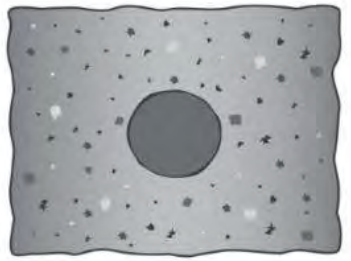
Or…

…if it is already like this, how do we fix it?

Reinforced Concrete Corrosion: Time until Damage

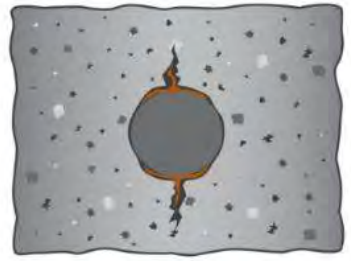


Stage 1 (Chloride Ingress)



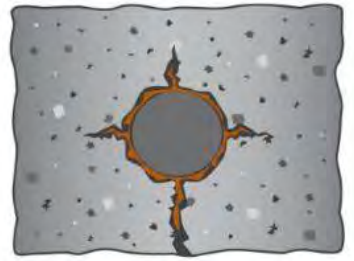
BEFORE CORROSION.

Stage 2 (Internal Damage)



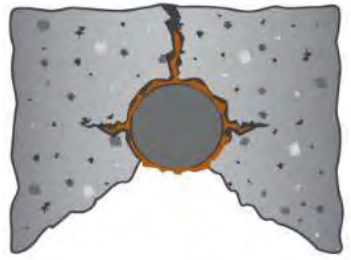
BUILD-UP OF CORROSION PRODUCTS.

Stage 3 (Surface Damage)



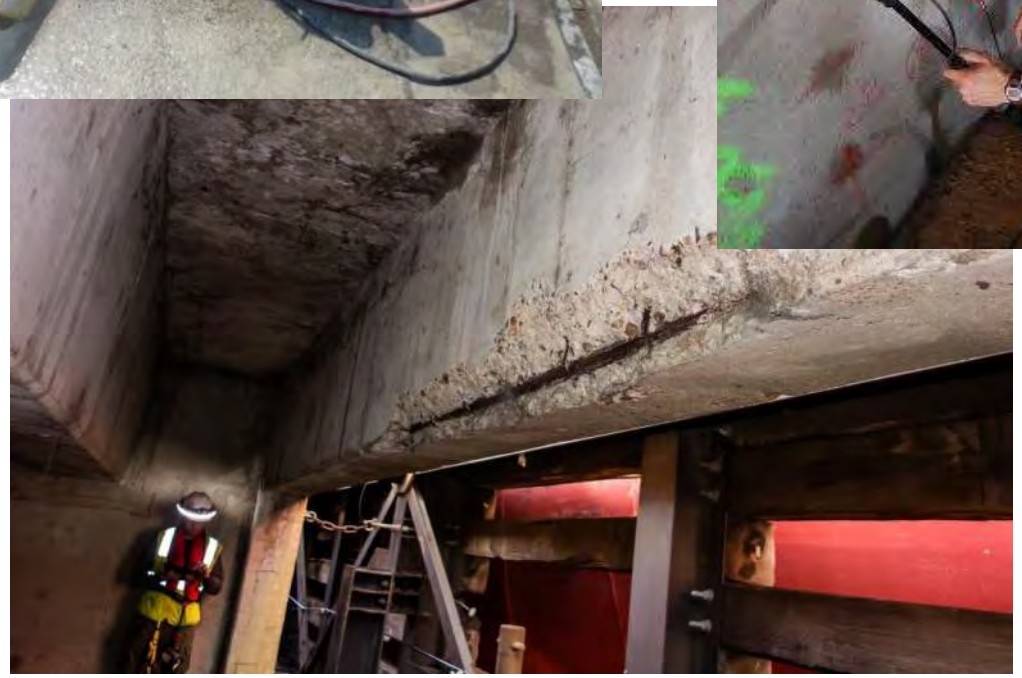
FURTHER CORROSION. SURFACE CRACKS. STAINS.

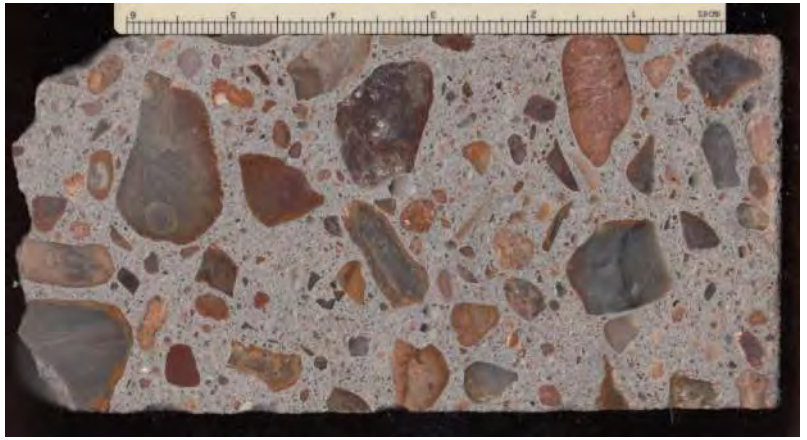
Stage 3++ (Advanced Damage)



EVENTUAL SPALLING. CORRODED BAR. EXPOSED.

Ask the Structure → In-depth Corrosion Assessment





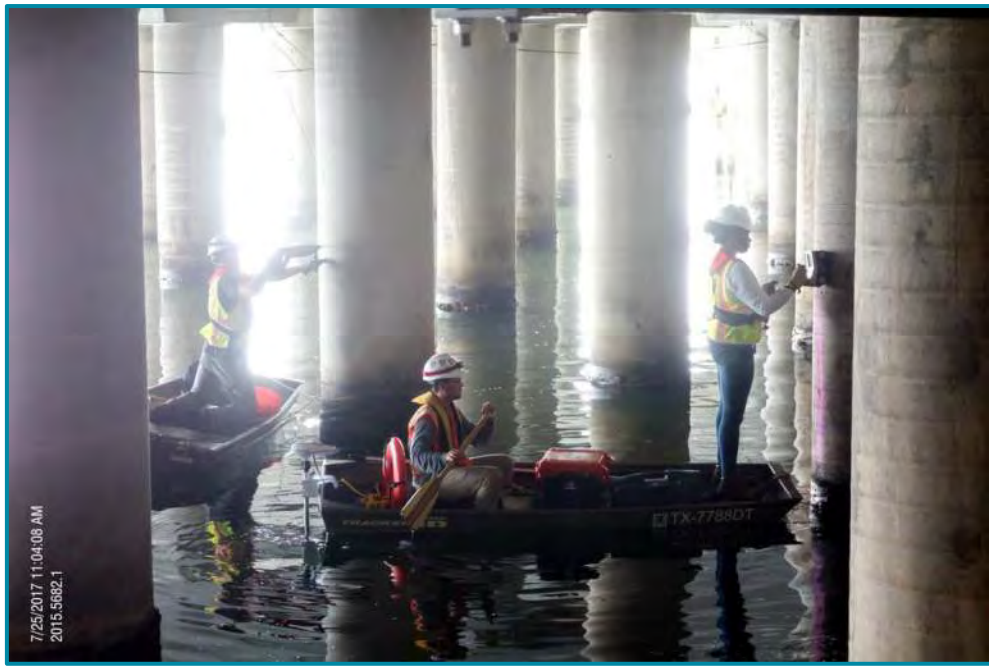
Field Investigation

Laboratory Evaluation

In-depth Corrosion Investigation

- Corrosion assessment requires a more detailed understanding of current condition

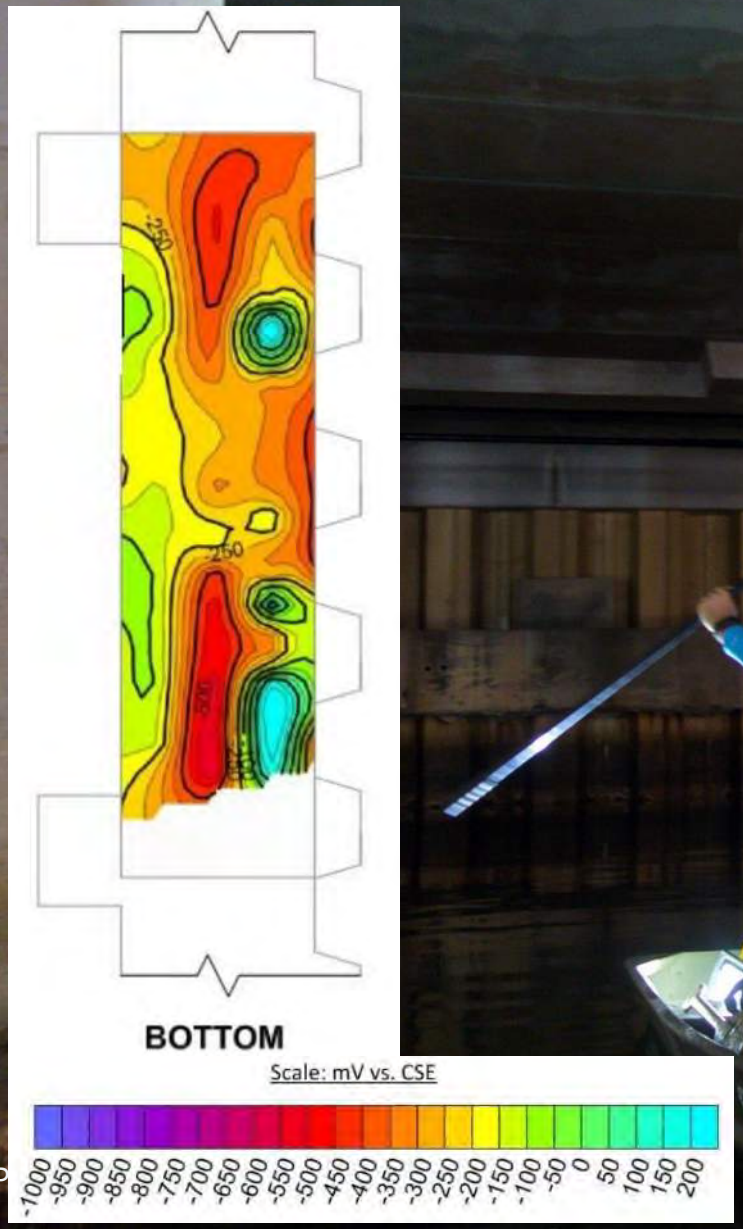
- Typically involves:
  - Visual assessment
  - Delamination survey
  - Nondestructive evaluation
  - Material sampling and testing



Visual Survey

- Observe conditions on 100% of structure
- Delamination survey (min. 10% of structure)
- Identifies representative areas for more in-depth investigation

Half-Cell Potentials



- Indicates corrosion risk in areas with no outward signs of corrosion damage
- Half-cell potential contour maps indicate corrosion “hot spots”
- Interpretation:
  - ASTM C876
  - Rilem TC-154

Corrosion Rate Measurements

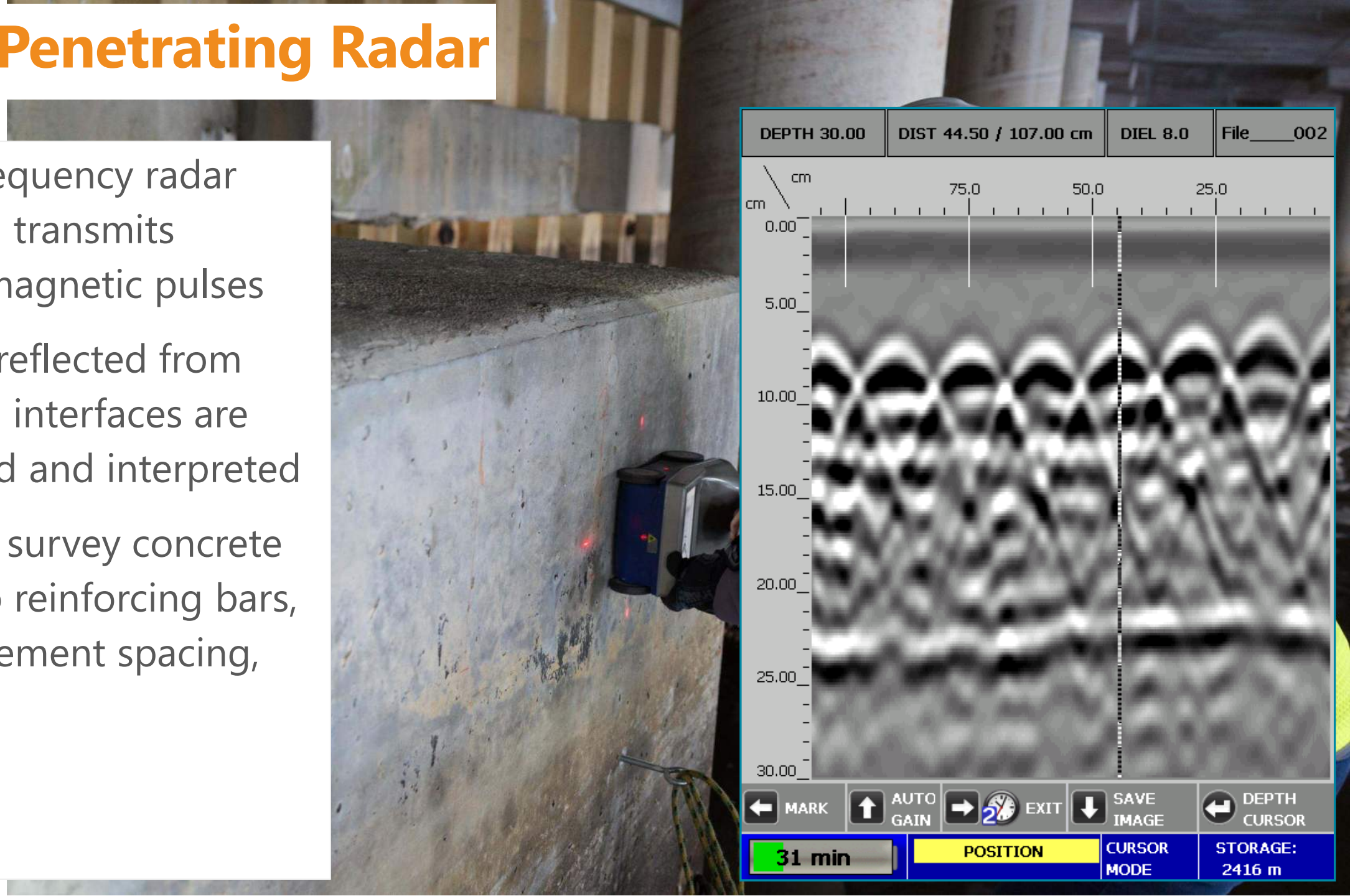
- Identify areas of active corrosion
- Indicate corrosion rate ($\mu A/cm^2$) based on measured polarization resistance
- Various commercial devices are available for corrosion rate

Concrete Surface Resistivity

- Correlates with risk of corrosion
- Supplements information from half-cell potentials and corrosion rate measurements

Ground Penetrating Radar

- High-frequency radar antenna transmits electromagnetic pulses
- Signals reflected from material interfaces are collected and interpreted
- Used to survey concrete cover to reinforcing bars, reinforcement spacing, etc.



Concrete Core Sampling

- Core sample extraction
  - Different elements
  - Exposure conditions
- Laboratory analysis:
  - Compressive strength
  - Chloride content profiles
  - Carbonation depth
  - Petrographic examination

Petrographic Examination of Concrete Cores

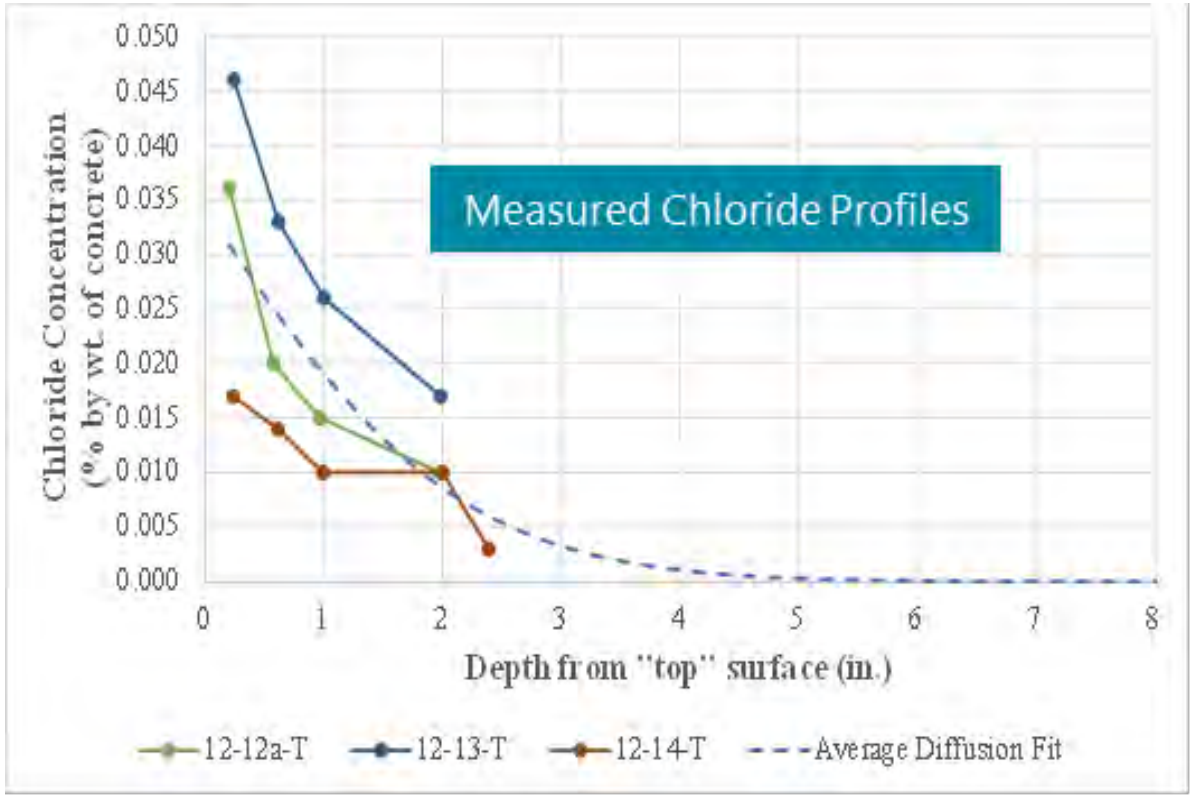
- Assess composition and quality of concrete
- Identify concrete distress mechanisms:
  - Alkali-silica reactions (ASR)
  - Sulfate attack
  - Salt hydration distress
  - Freeze-thaw damage

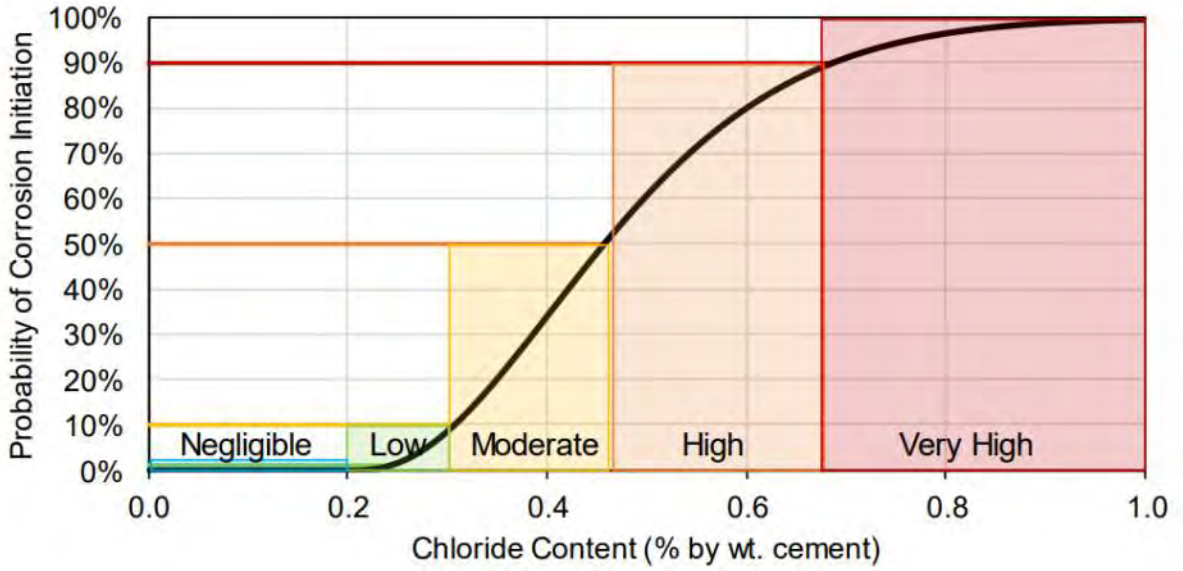
Alkali-Silica Reaction Distress

Concrete Chloride Content Analysis from Cores

- Perform chemical analysis to determine **concrete chloride level** at increasing depth from surface
  - Defines "chloride profile"
  - Establish for different elements of structure and different exposure zones

- Chloride levels correlate with risk of corrosion

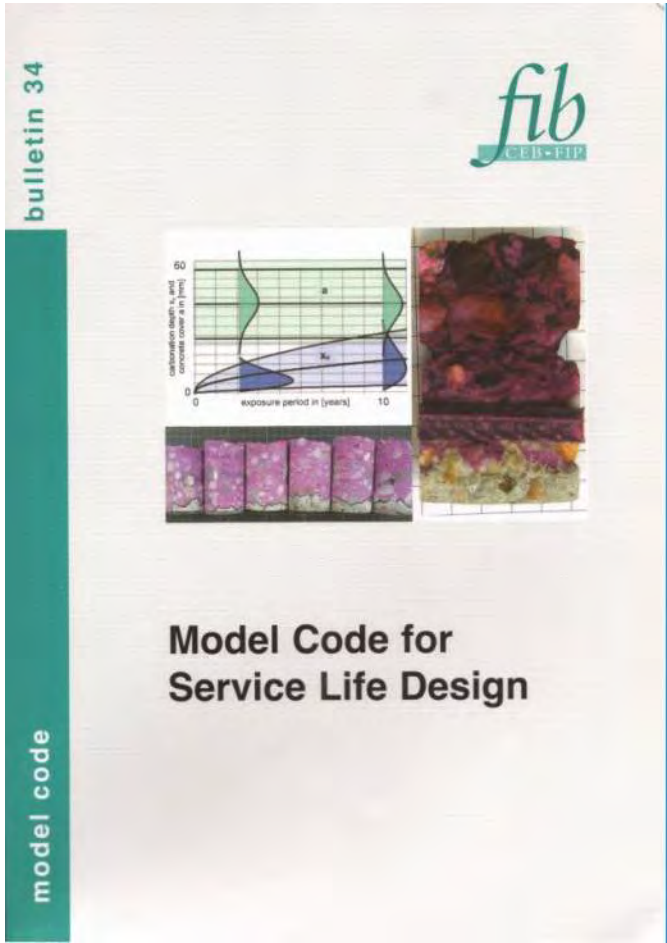




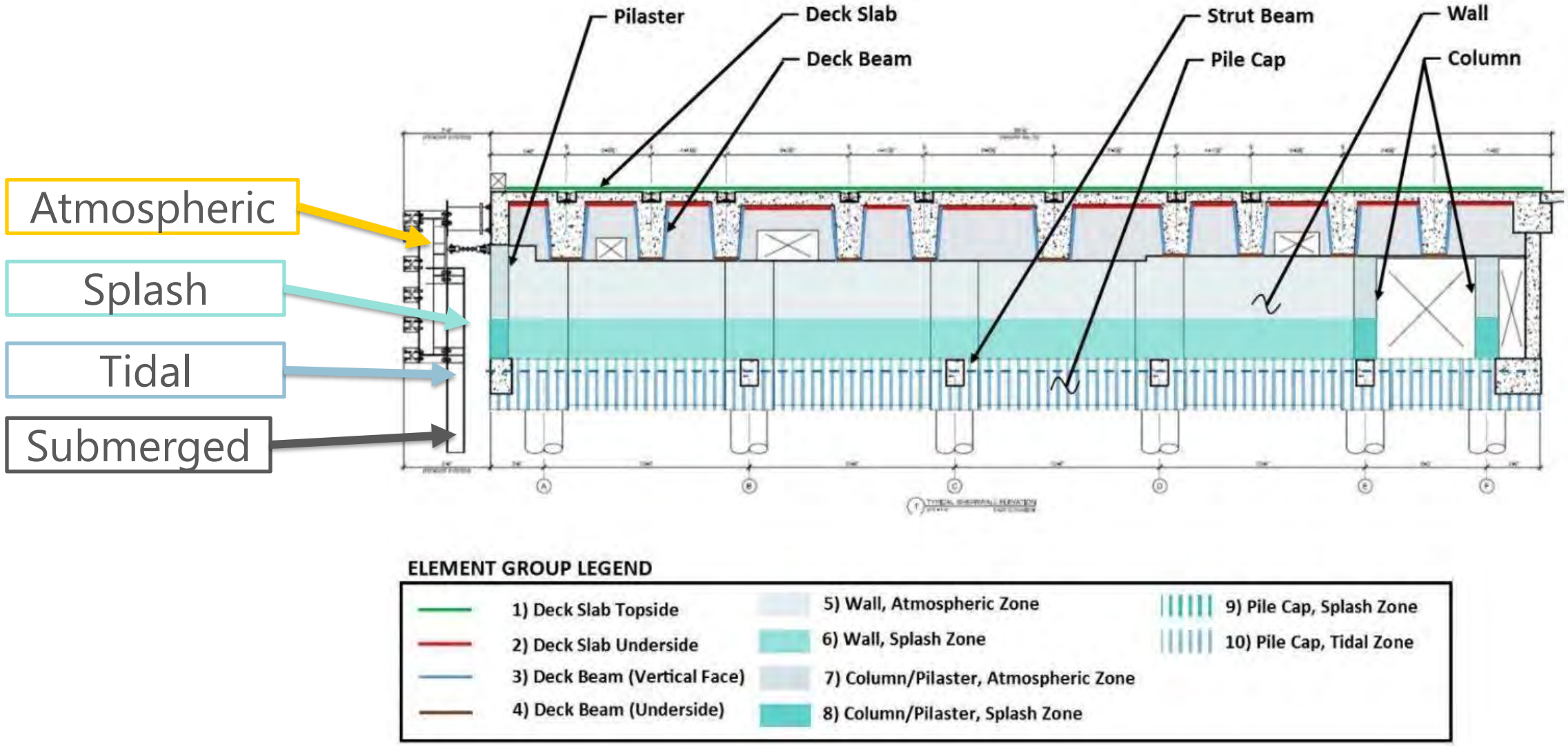
Evaluation of Remaining Service Life

- In-depth field and laboratory investigation supports **service life modeling**
  - What is remaining life before a damage threshold is exceeded
  - Evaluate effectiveness of repair materials and protective systems to extend service life

- WJE in-house corrosion analysis model: **CASLE™**
  - **Corrosion Assessment and Service Life Evaluation**
  - Full probabilistic approach:
    - Monte Carlo simulation used to estimate progression of corrosion damage based on statistical inputs
    - Many inputs defined using in-depth field and laboratory investigation



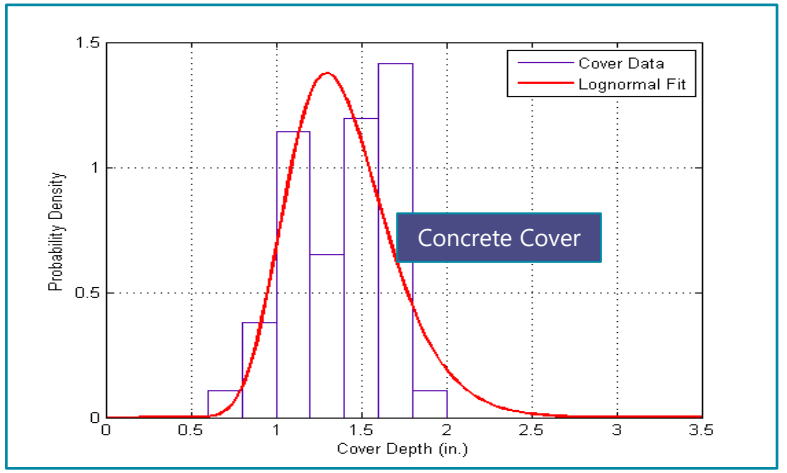
Service Life Modeling: Exposure Zones

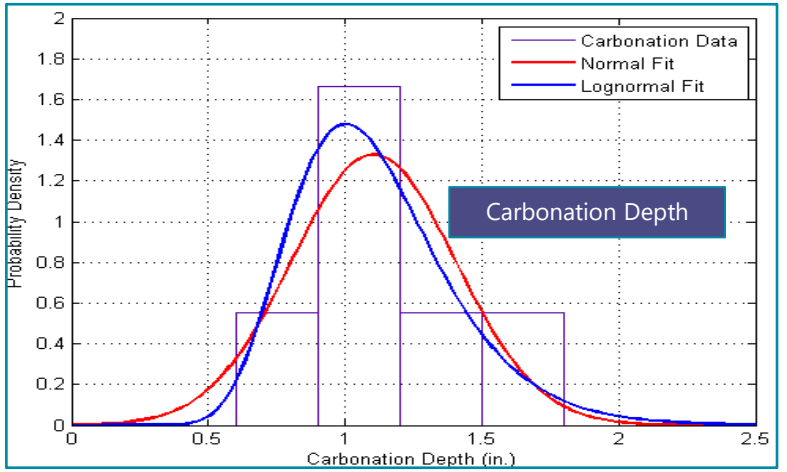


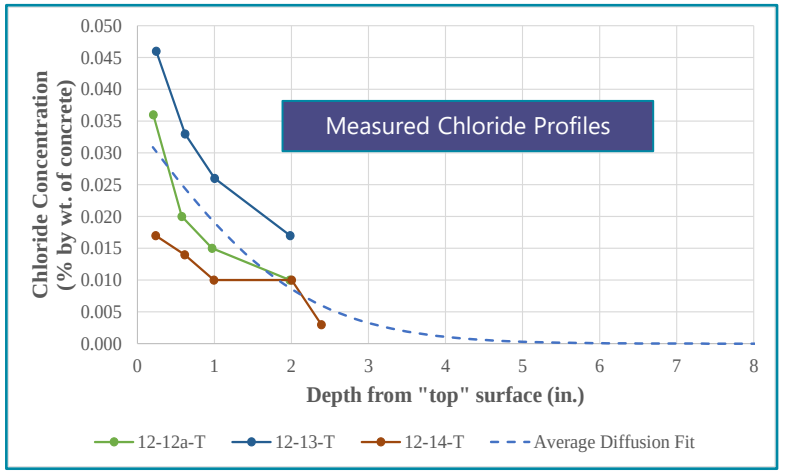
Service Life Modeling: Inputs

- Age of structure
- Concrete properties modeled statistically
  - Concrete cover to reinforcement*
  - Carbonation levels* and rate
  - Chloride profiles* and threshold
- Exposure conditions by element
  - Exposure zone
  - Environmental chloride levels at project site
  - Surface concentration* and diffusion of chlorides and CO_2
- **Design Parameters:** Concrete materials, cover, reinforcement type, cathodic protection, etc.

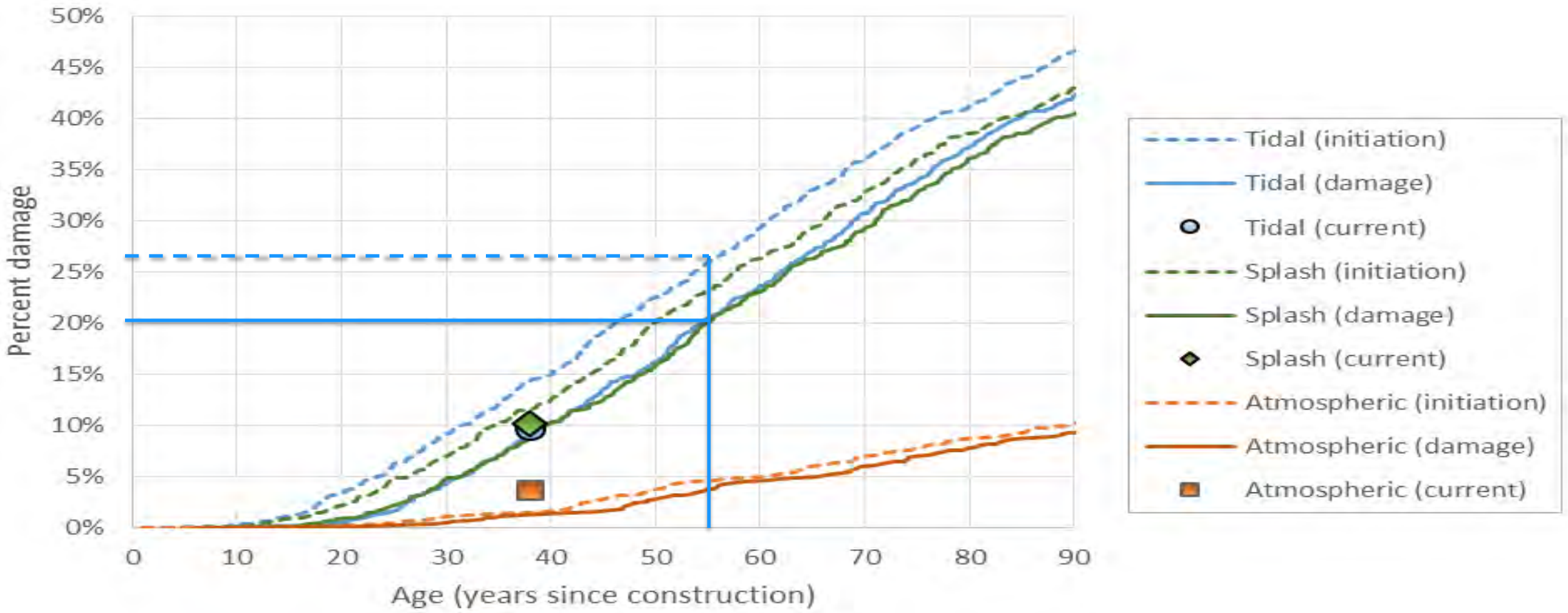
*** from in-depth assessment**







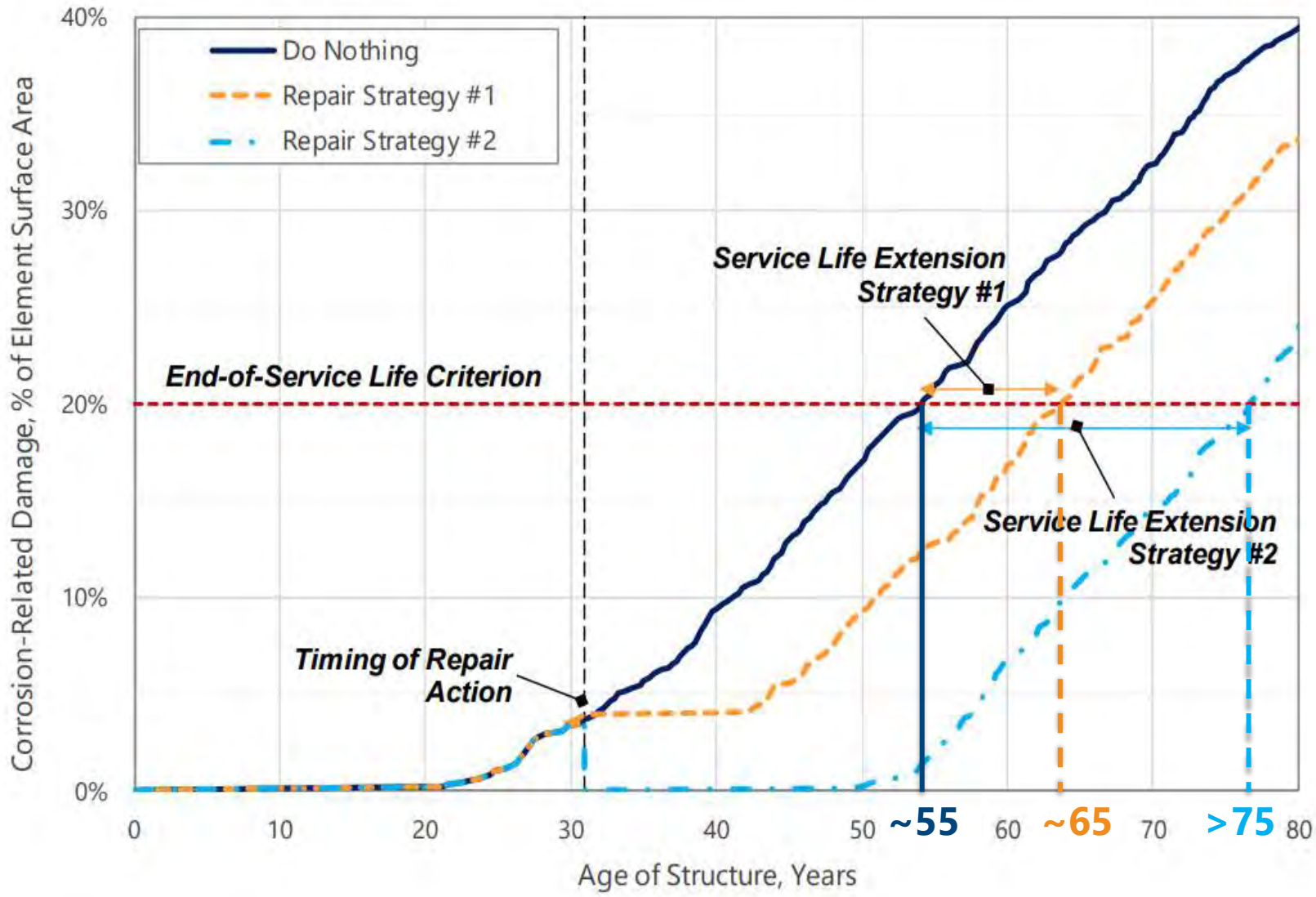
Service Life Modeling: Prediction of Damage Over Time



In-Depth Corrosion Assessment

- In-depth corrosion investigation and service life modeling **supports improved decision making**
  - Timing of repairs
  - Selection of repair methods and protection measures

WJE CASLE™

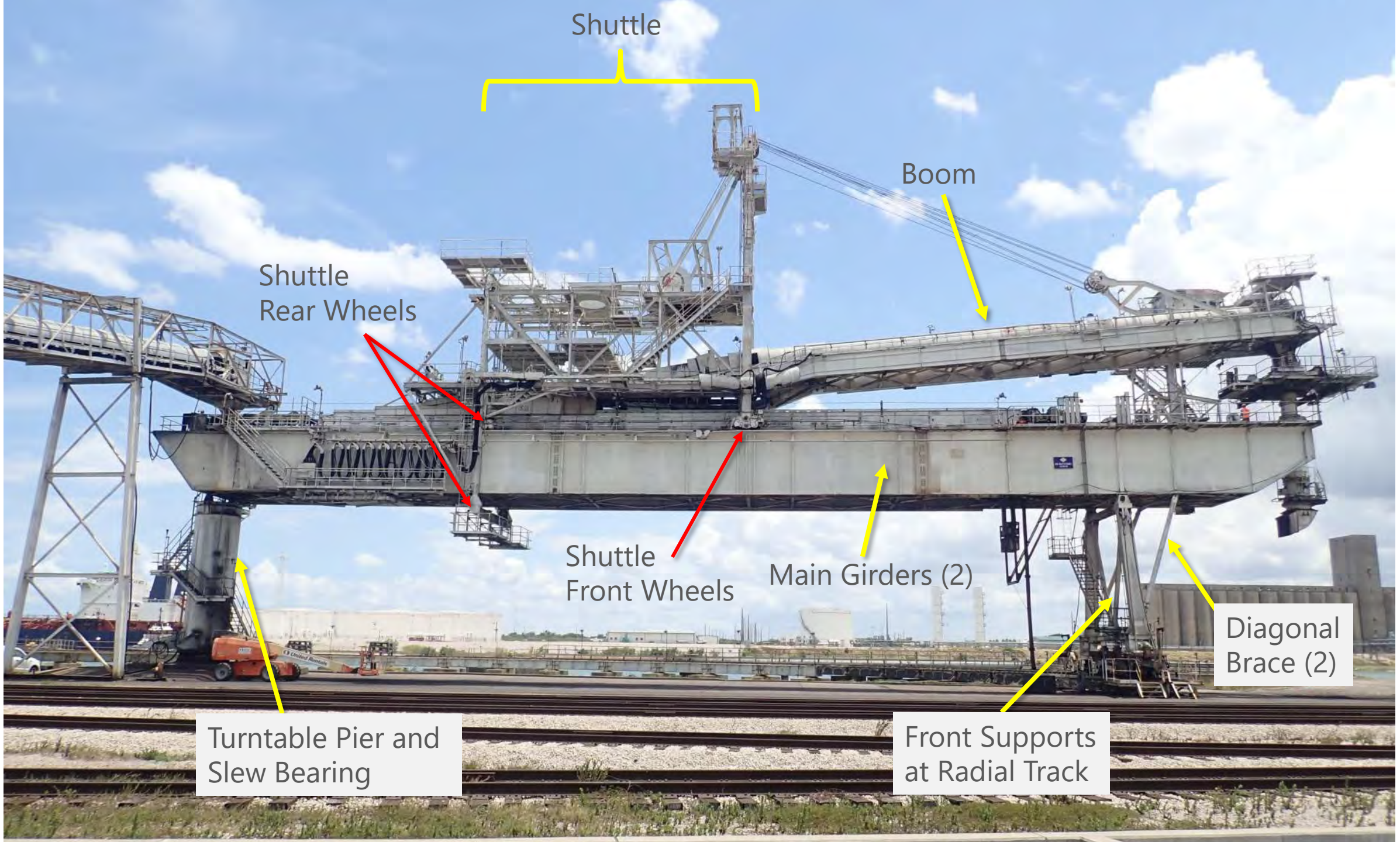


Beyond the Routine:
Shiploader Fatigue Evaluation

Bulk Material (Petroleum Coke) Shiploader at Gulf Coast Export Terminal


G L A N D


Shiploader
Turntable pier
Radial Track
Google Earth


Shuttle
Boom
Shuttle
Rear Wheels
Shuttle
Front Wheels
Main Girders (2)
Diagonal
Brace (2)
Turntable Pier and
Slew Bearing
Front Supports
at Radial Track

Motivation for Project

- Rail replacement project in January-February 2022
- Corrosion-induced section loss observed on top flanges of plate girder
  - Worst locations had 10% to 15% reduction in girder section modulus
  - Most locations <10% reduction in S_{xx}

Possible Consequences of Corrosion-Induced Section Loss

- Increased stress ranges are expected
- May affect girder long-term fatigue performance and safety
- Challenge:
  - Shuttle and boom selfweight and loads on girders during vessel loading operations are **not known**
  - Effect of flange section loss cannot be determined by analysis

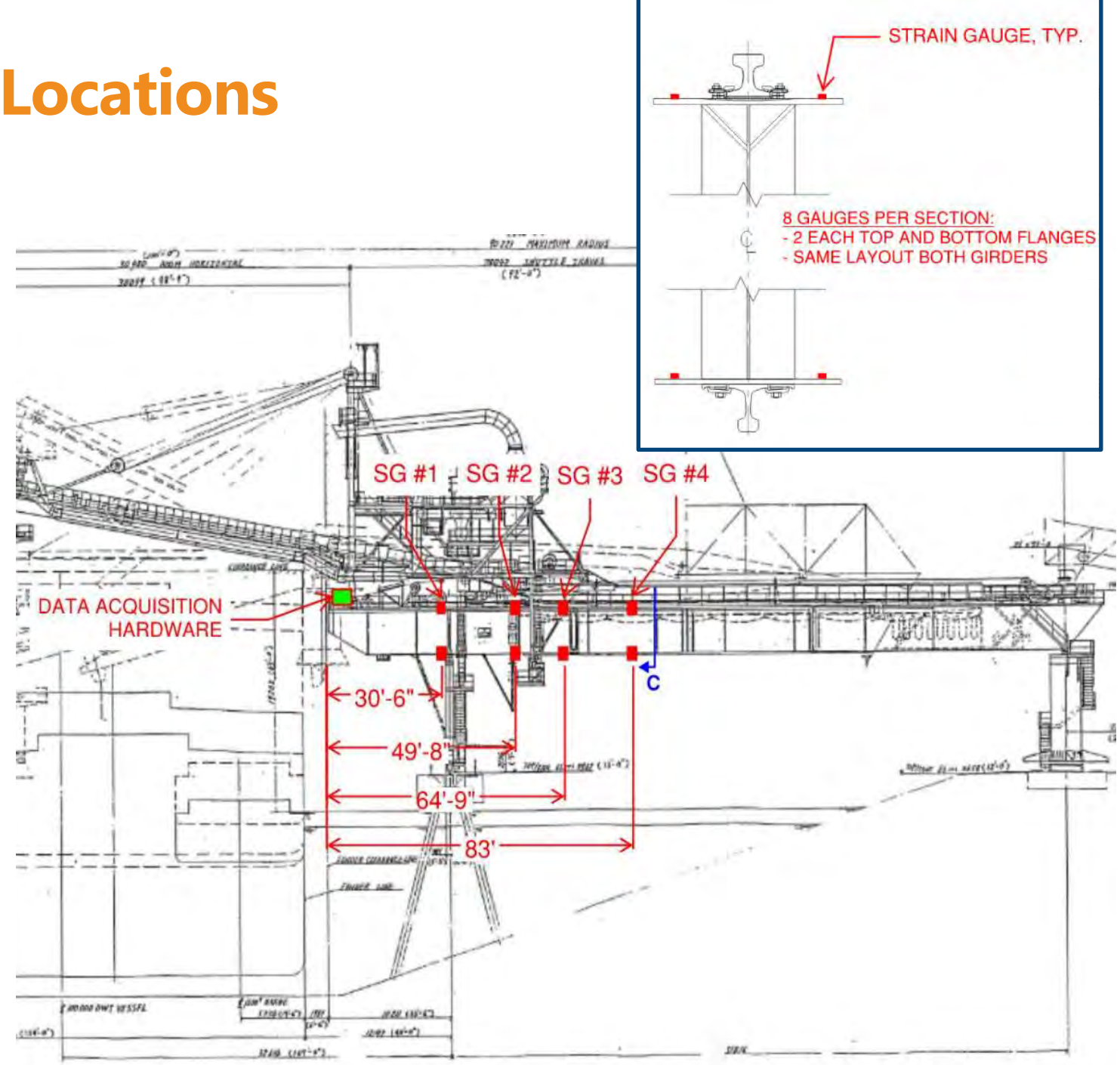
Stress ranges during shiploader operation need to be measured by instrumentation and monitoring to facilitate fatigue analysis

Approach

- Install strain gages at critical locations to measure response
- Record girder strain response for multiple vessel loadings
- Estimate number of vessel loading events over life of shiploader
- Calculate remaining fatigue life using AASHTO Manual for Bridge Evaluation (MBE)
  - Account for corrosion section loss and actual operating and loading conditions

Determine Strain Gage Locations

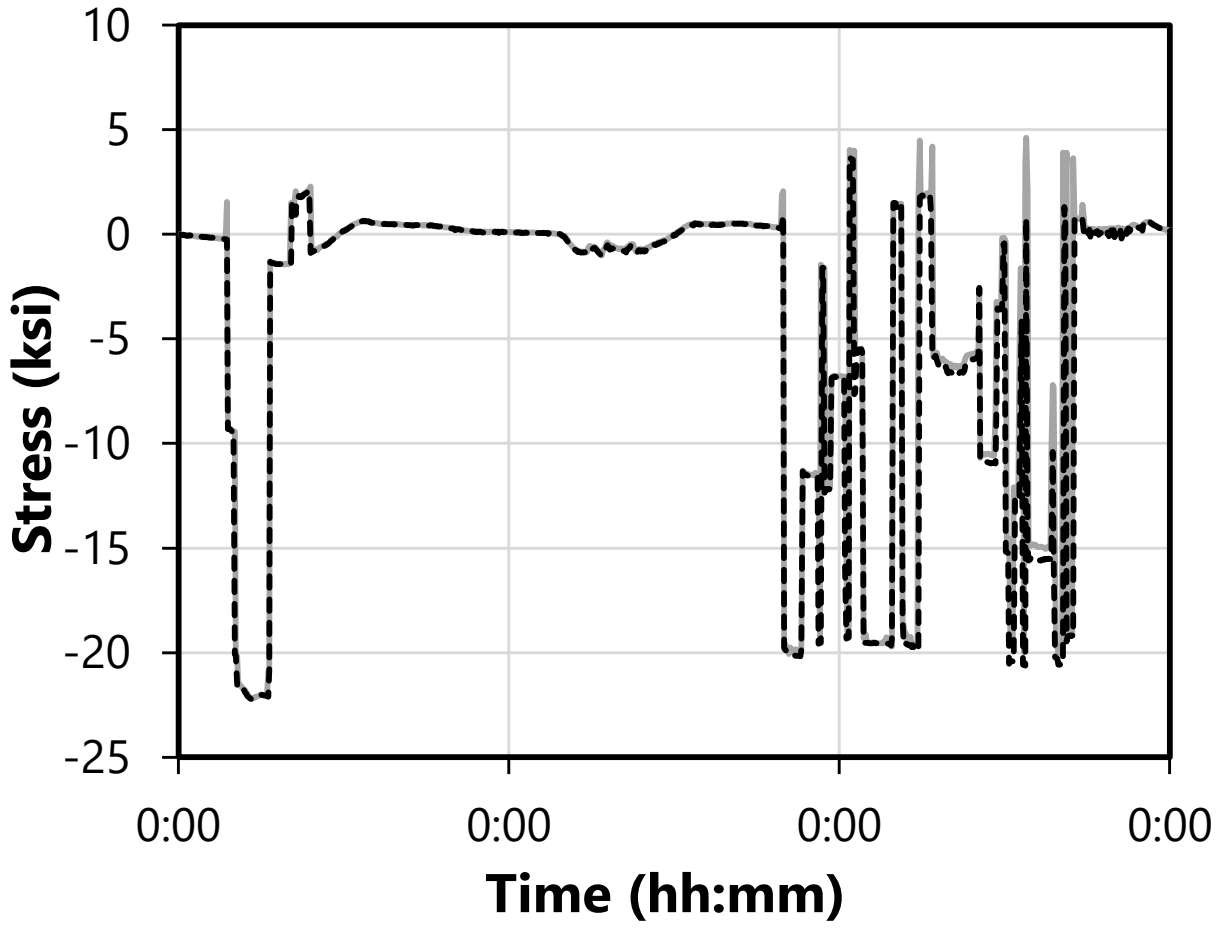
- Strain gage locations were determined by analysis
  - Critical sections occur at changes in flange plates
- Gages installed on girder flanges
  - Two strain gauges installed on top and bottom flange at each location on each girder
  - 32 gauges total



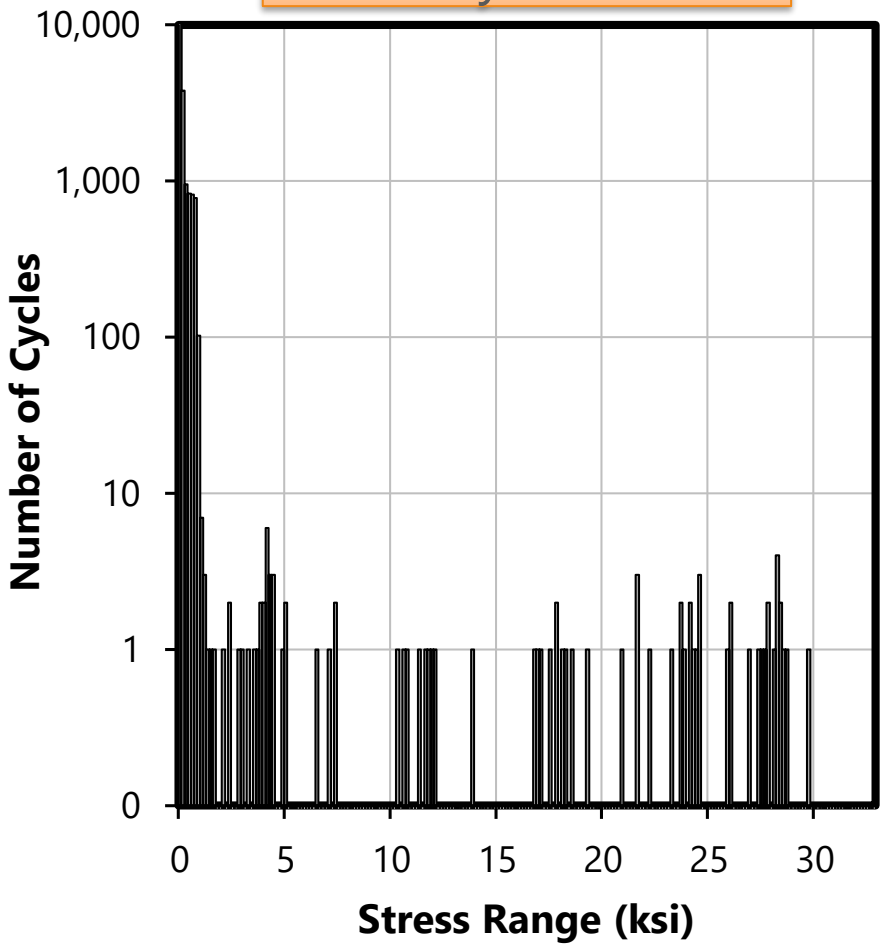
Examples of Strain Gages

Typical Stress Response from Vessel Loading Event

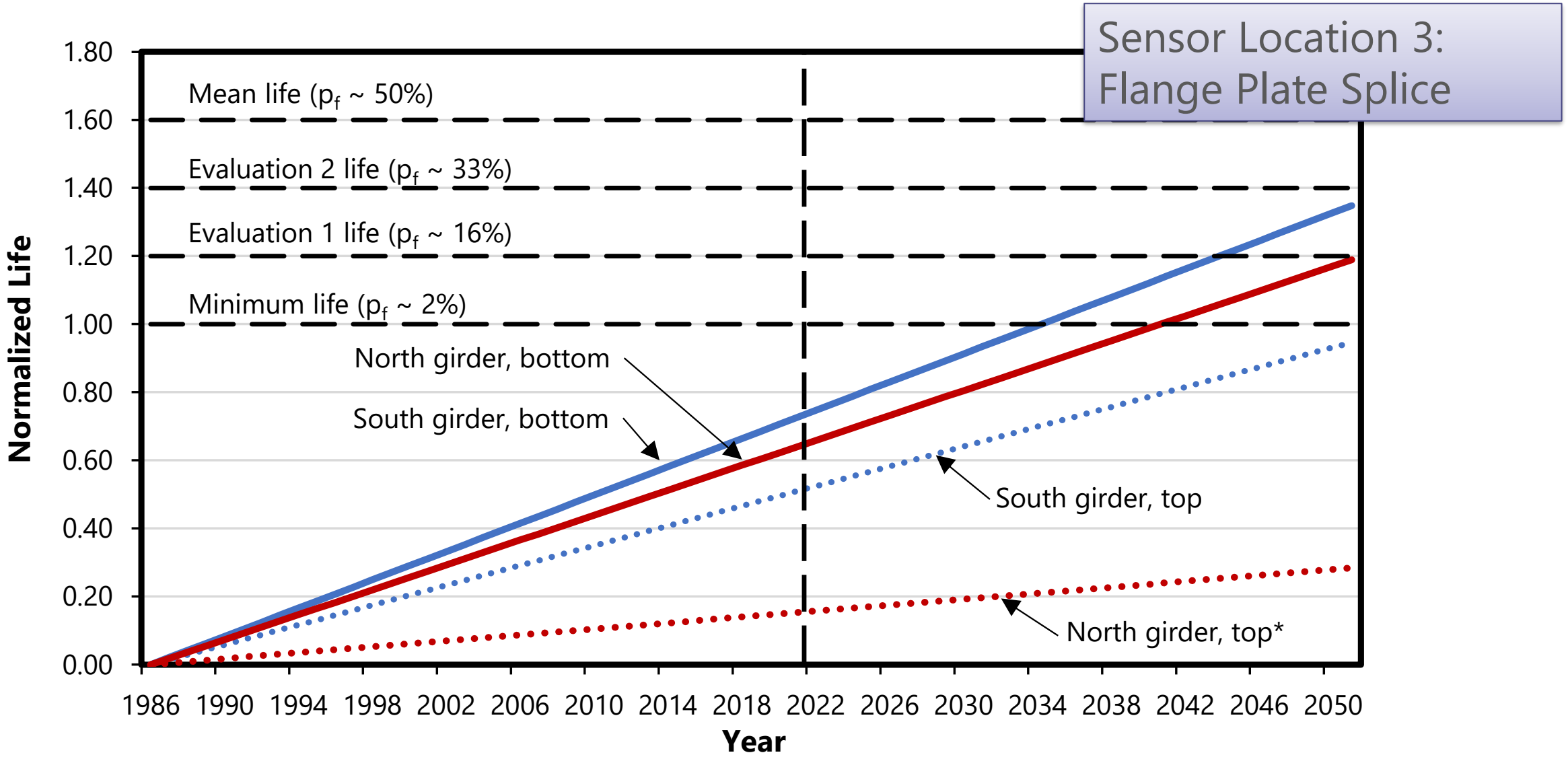
Stress Time History



Stress Cycle Counts



Predicted Fatigue Life – Brace Connection



Conclusions

- Estimated fatigue life has not reached "Minimum Life" (p_f = 2%)
  - Very low risk of fatigue cracks at present
- No immediate concern for fatigue damage
- Future management
  - Inspections at regular intervals (every 5 to 10 years), repair as necessary
  - Preemptively repair to change details, reduce stress ranges, or both

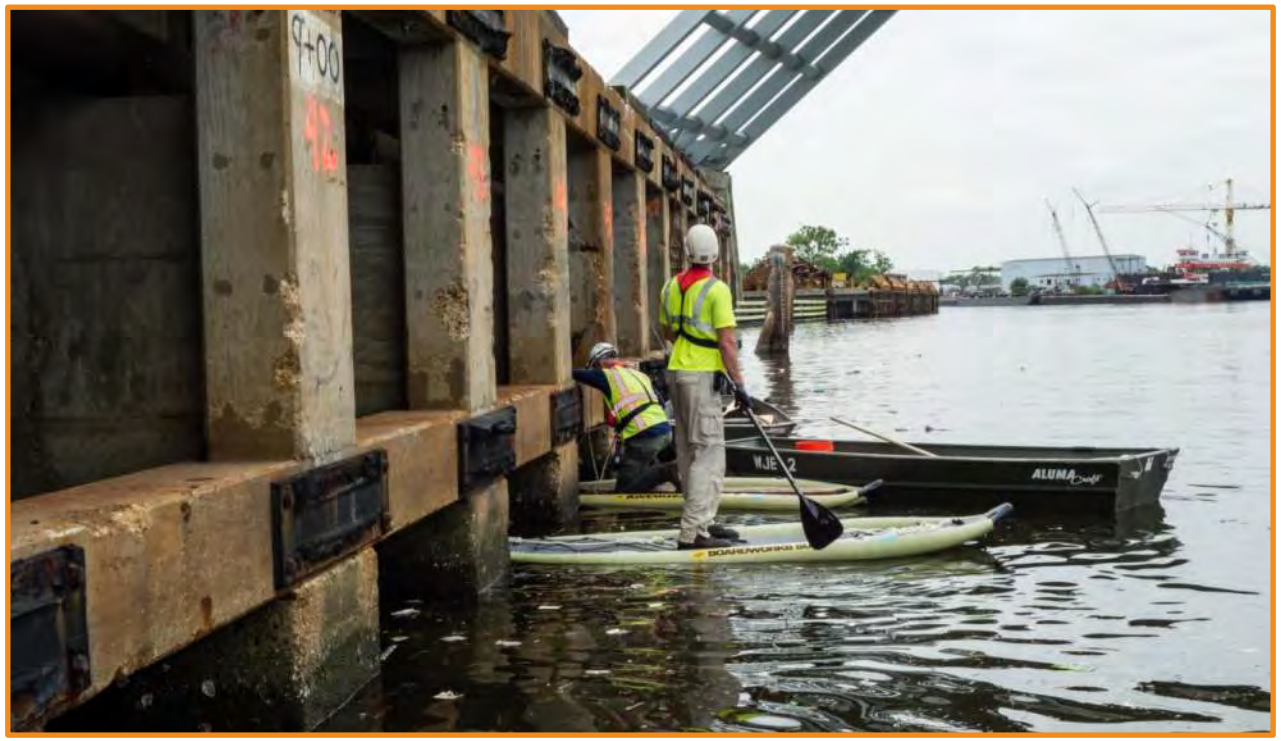
Beyond the Routine:
Wharf Substructure Evaluation

Rehabilitation of Liquid-bulk Wharf with 100-Year-Old Timber Piles

Manchester Terminal Wharf 2 (Port Houston)

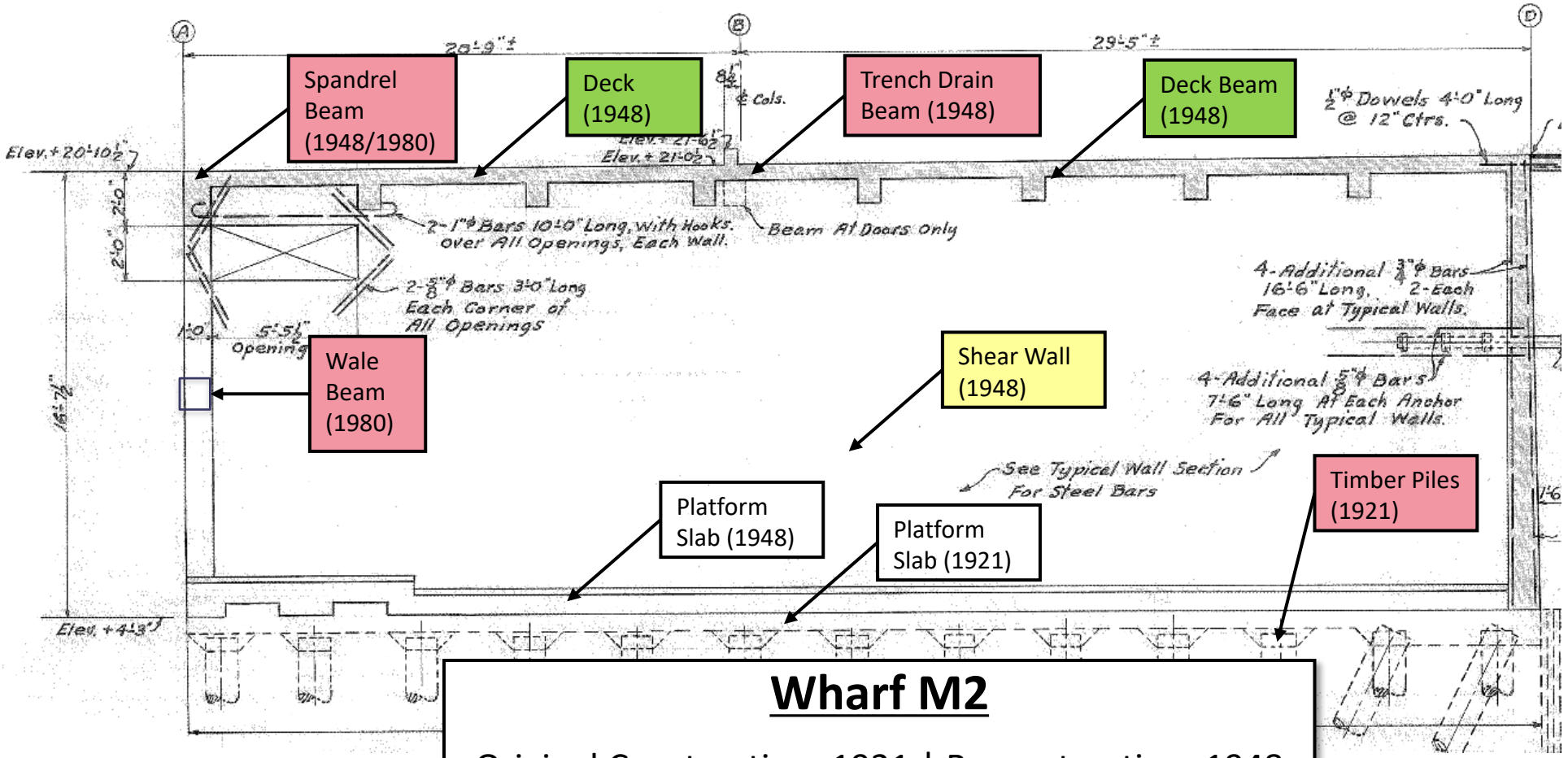
- Liquid-bulk facility
  - 20 ft. accessibility area
  - Limited live loads (300 psf)
  - Light-duty forklifts
- Built in 1920s
  - 500 ft. long
  - 50 ft. wide
  - Concrete superstructure
  - Timber substructure

What is current condition?
Can we deepen channel?



Typical Bent Structure

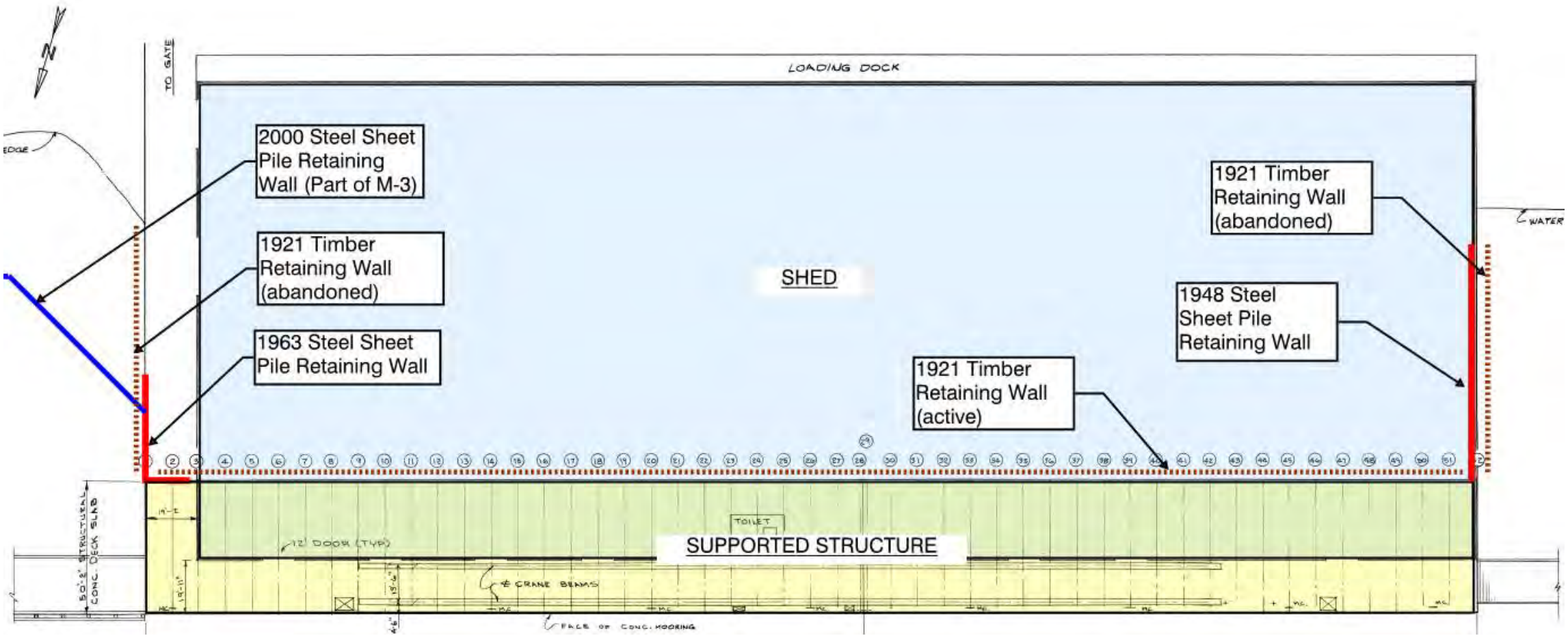
- 52 bents



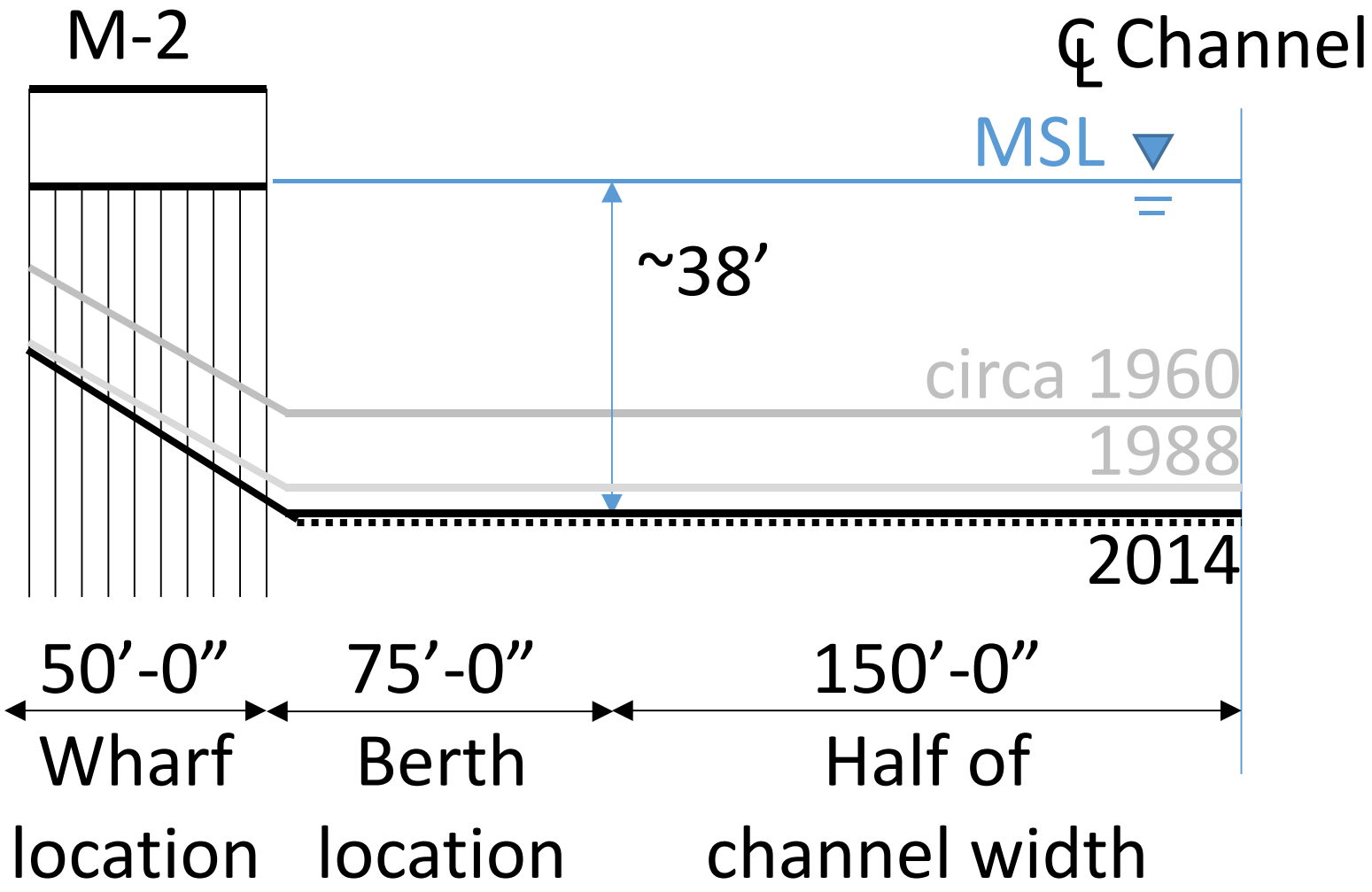
Wharf M2

Original Construction: 1921 | Reconstruction: 1948
Gantry Crane: 1970 | Repairs: 1981

Plan View


LOADING DOCK
TO GATE
2000 Steel Sheet Pile Retaining Wall (Part of M-3)
1921 Timber Retaining Wall (abandoned)
1963 Steel Sheet Pile Retaining Wall
SHED
1921 Timber Retaining Wall (abandoned)
1948 Steel Sheet Pile Retaining Wall
1921 Timber Retaining Wall (active)
WATER
TOILET
12' DOOR (TYP)
SUPPORTED STRUCTURE
℄ CRANE BEAMS
FACE OF CONC. MOORING

History of Dredge Depth



Condition of Superstructure

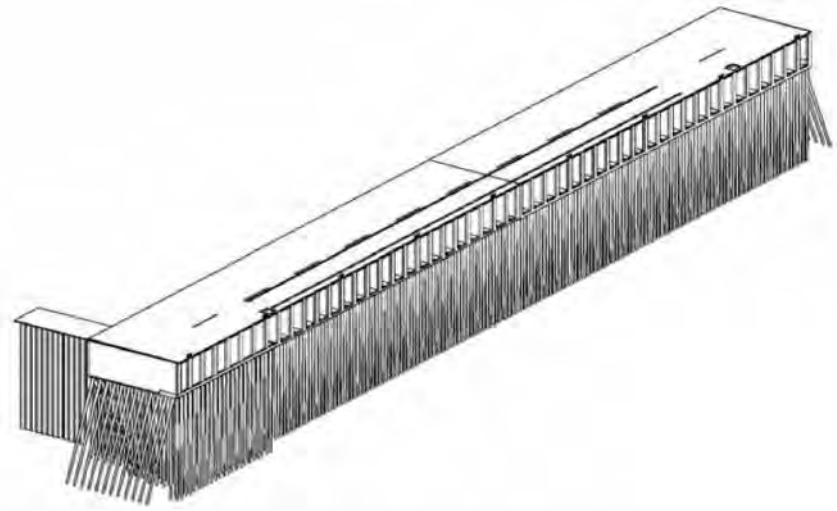
- Corrosion/section loss from ship impact and exposure
- Retaining wall deterioration
  - Implications for slope stability?

Service Life Analysis

Element	Life Remaining (years)	Primary Deterioration Mechanism	Work Needed to Reach 50 years
Deck and typical deck beams	**50+**	Corrosion at cracks	Repairs and crack sealing
Trench drain beams	**End of life**	Corrosion	Replacement
Spandrel beams	**End of life**	Impact and corrosion	Replacement
Wale beams	**End of life**	Impact	Replacement
Front Pilasters	**End of life**	Impact and corrosion	Replacement
Fenders	**End of life**	Impact	Replace
Shear walls	<25 years	Corrosion	Replace / supplement
Retaining walls	**End of life**	Corrosion / decay	Replace / supplement
Piles	**?**	?	?

Condition of Foundation

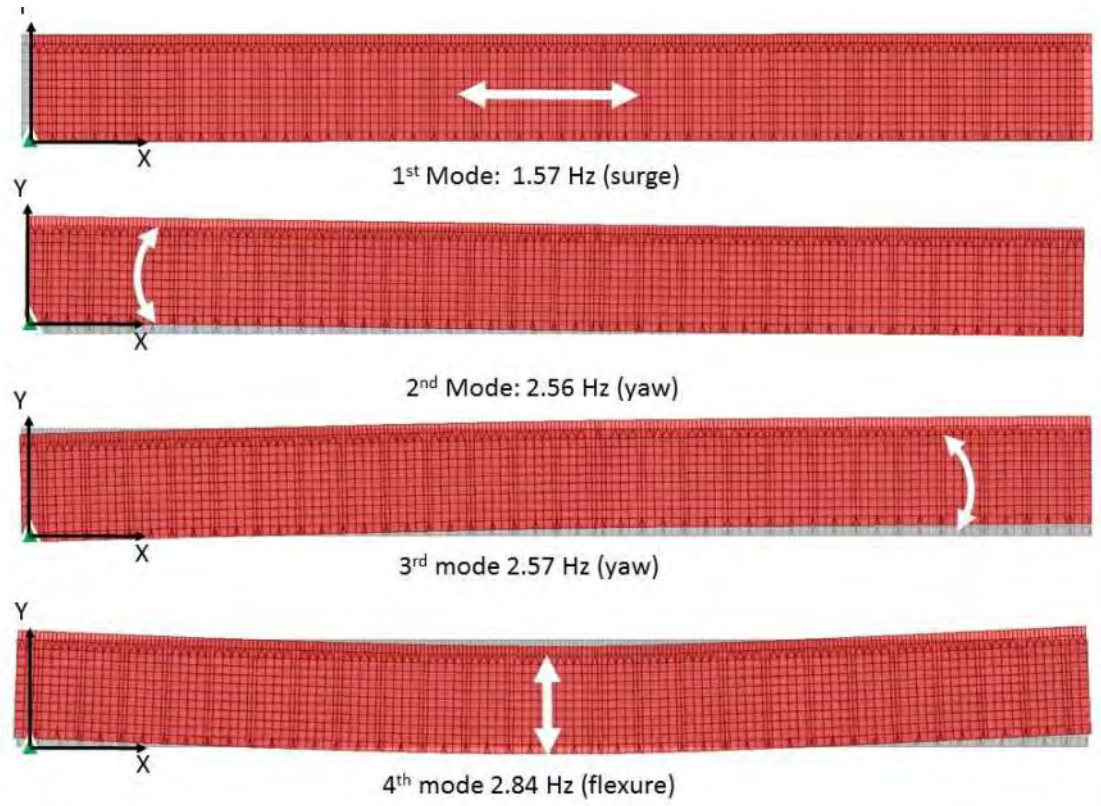
- Forest of piles (~4,000 piles)
  - Spacing: 2.5 ft. to 4 ft.
  - Only the perimeter piles (177) were inspected and sounded
- Divers noted
  - Circumference could be penetrated (1 inch for 95 percent of outer piles in the upper part and 1/2 inch at mid-length)
  - A batter pile was not connected to the shear wall
  - Portions of the piles could be peeled away



What is the impact of the pile deterioration?

Vibration Monitoring

- Instrument wharf with multiple sensors
- Impact wharf with barge and measure response ("impulse response")
- Develop three-dimensional computer model
  - Include soil-structure interaction
- Compare resonant modes of computer model to free-vibration response of wharf
  - Make adjustments to model for observed distress

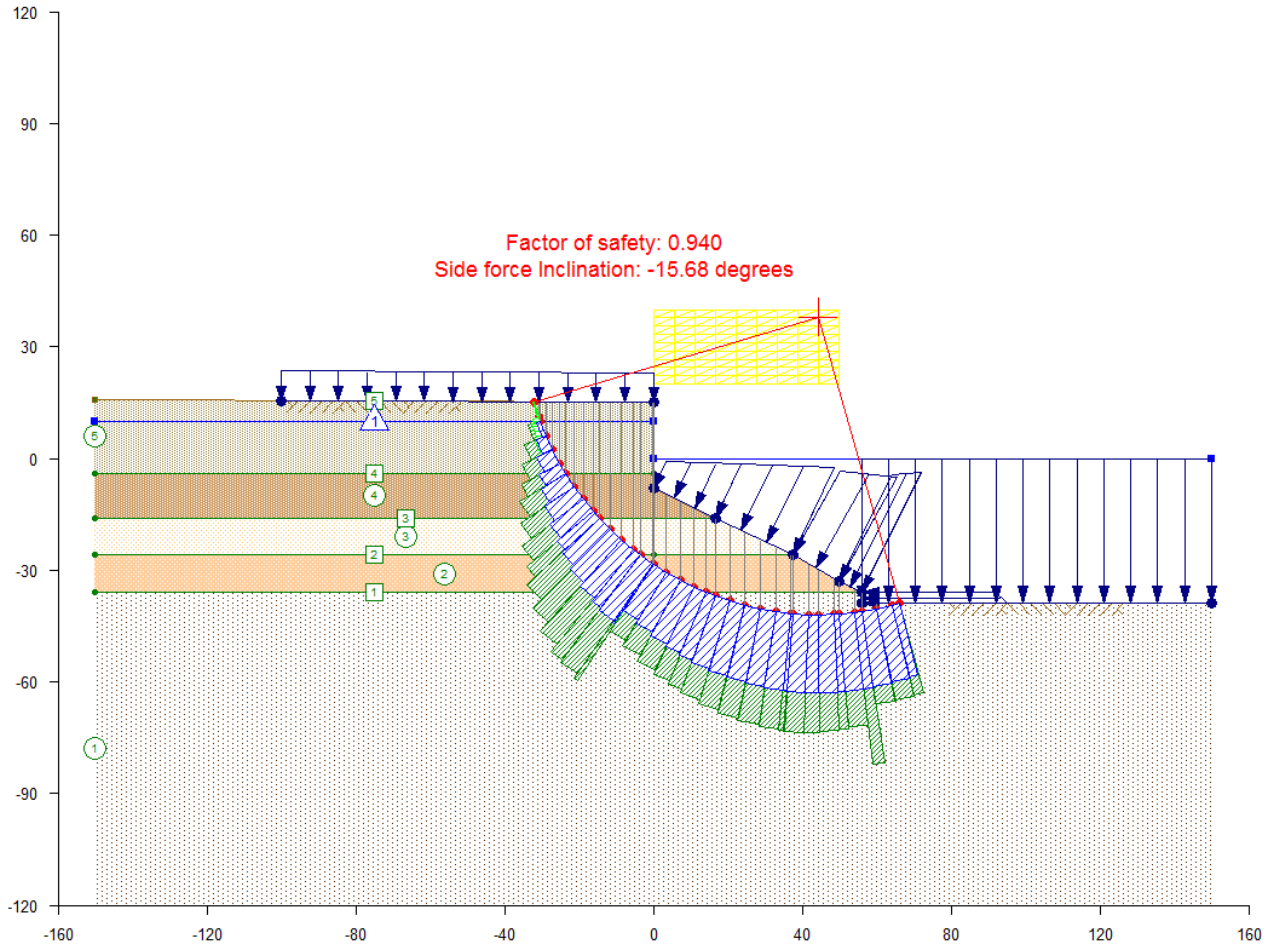


Calibration Results
(1) Use pins at top of piles
(2) Reduced flexural stiffness by ~50%

Slope Stability

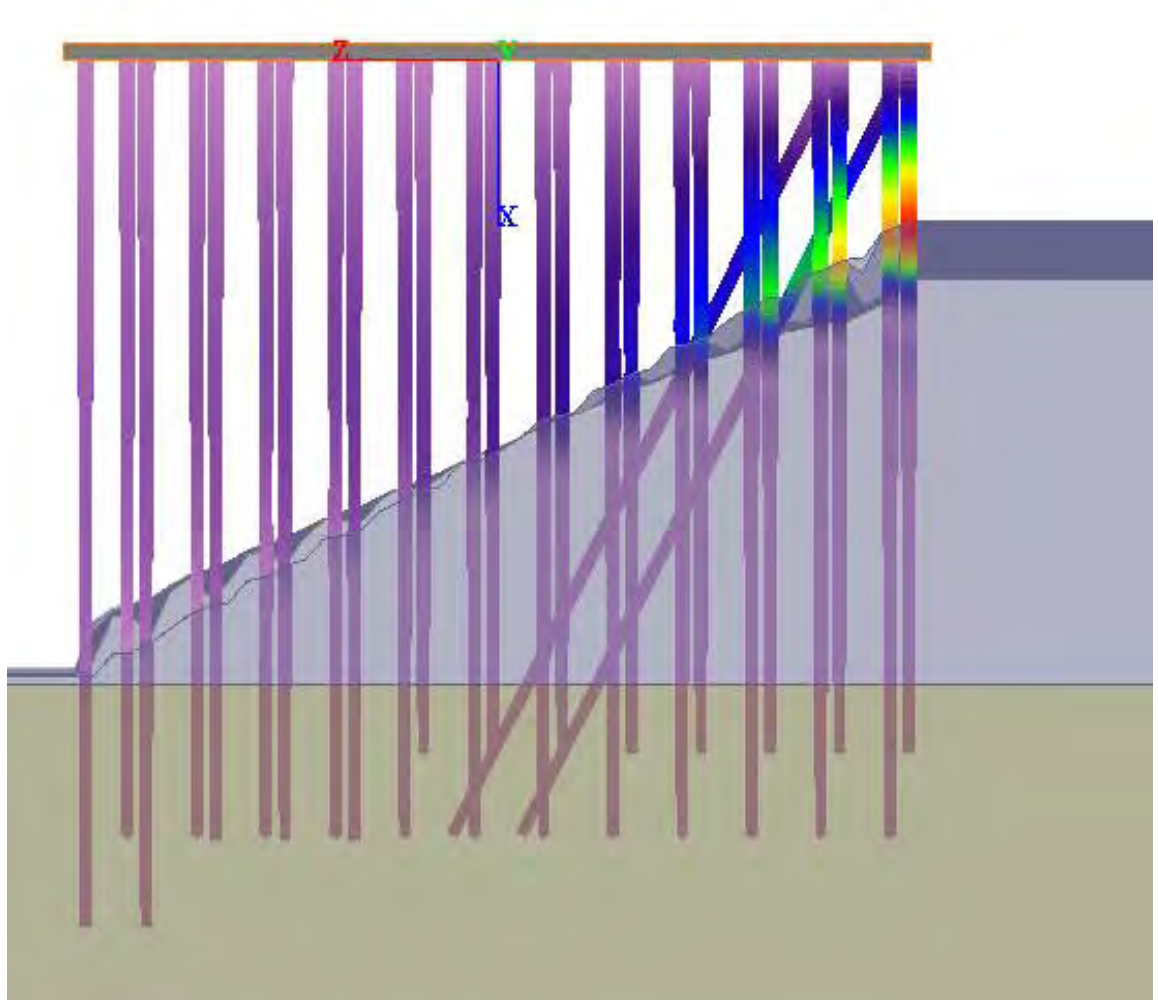
- OK for short term
- NG for long term

Item	Pre-2014	Post-2014
Short term	2.1	1.7
Long term	1.2	1.0



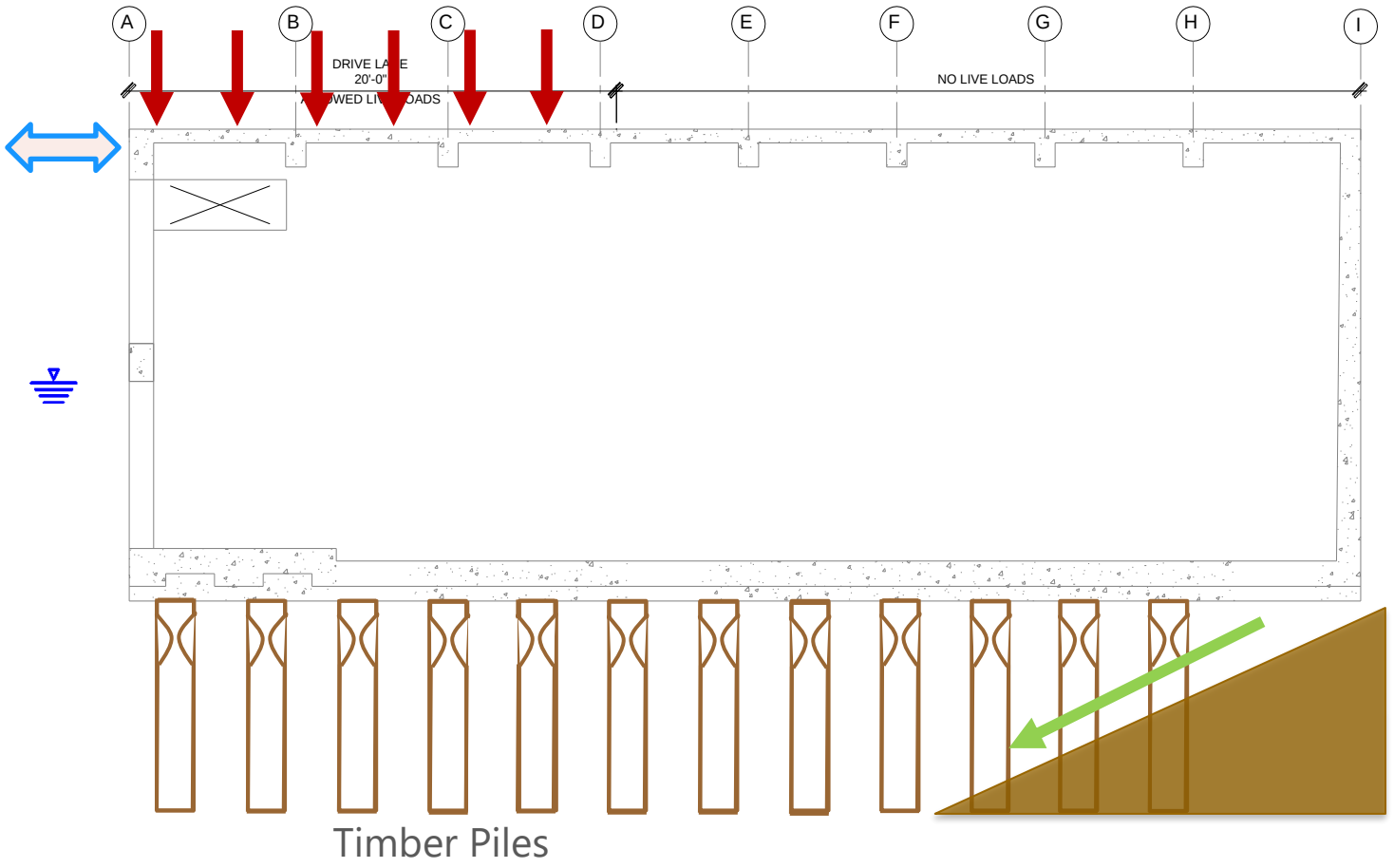
Load-Carrying Capacity

- Front lines of piles “overstressed”
  - Shear wall is stiff enough to redistribute load (OK for now)
- Lateral system NG
  - Large soil pressures (neglect tiebacks)
  - Large mooring loads
- Non-functional fender system



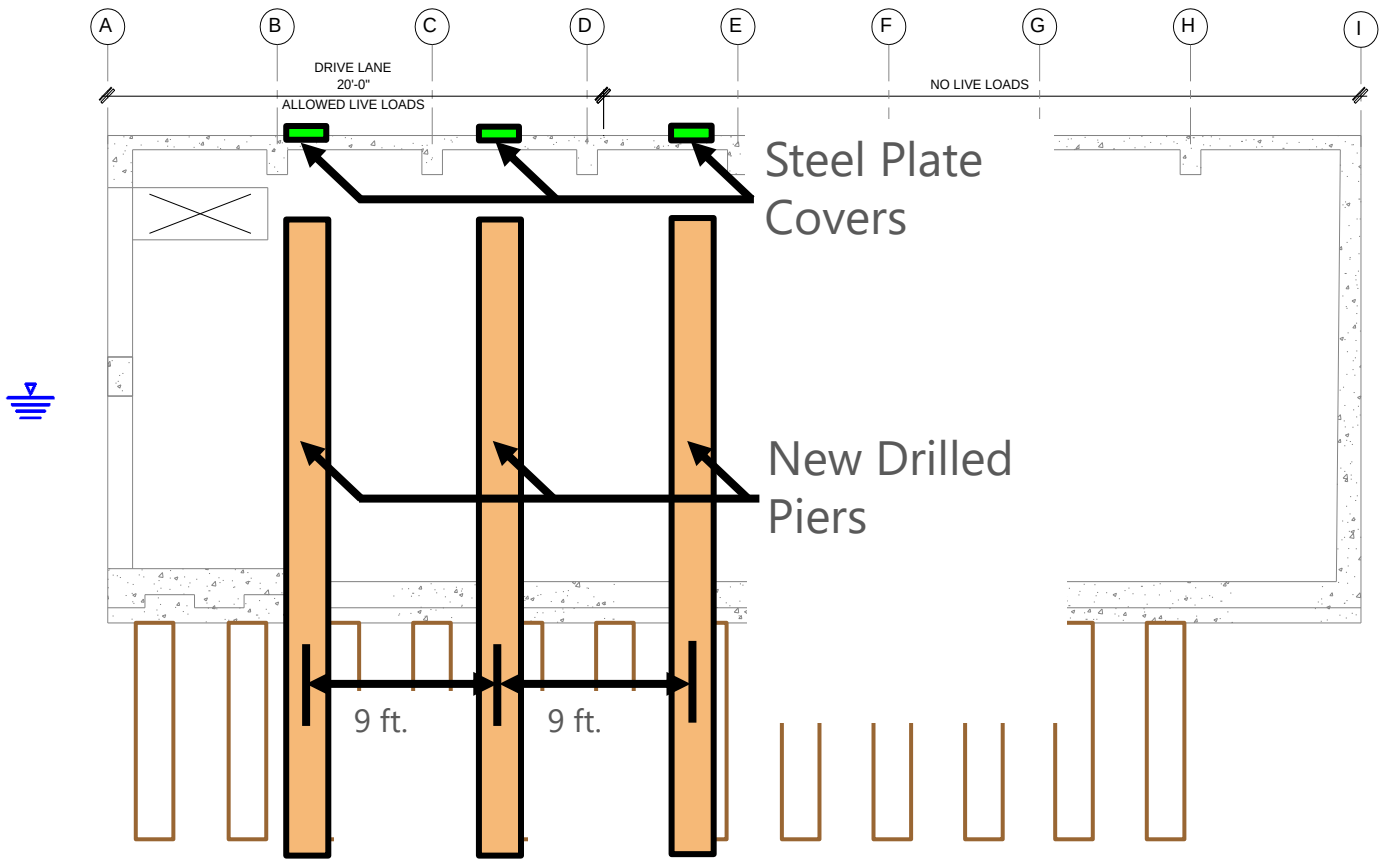
Repair Recommendations

- Highly utilized wharf
- Consider
  - Lateral loads
  - Gravity loads
  - Slope stability



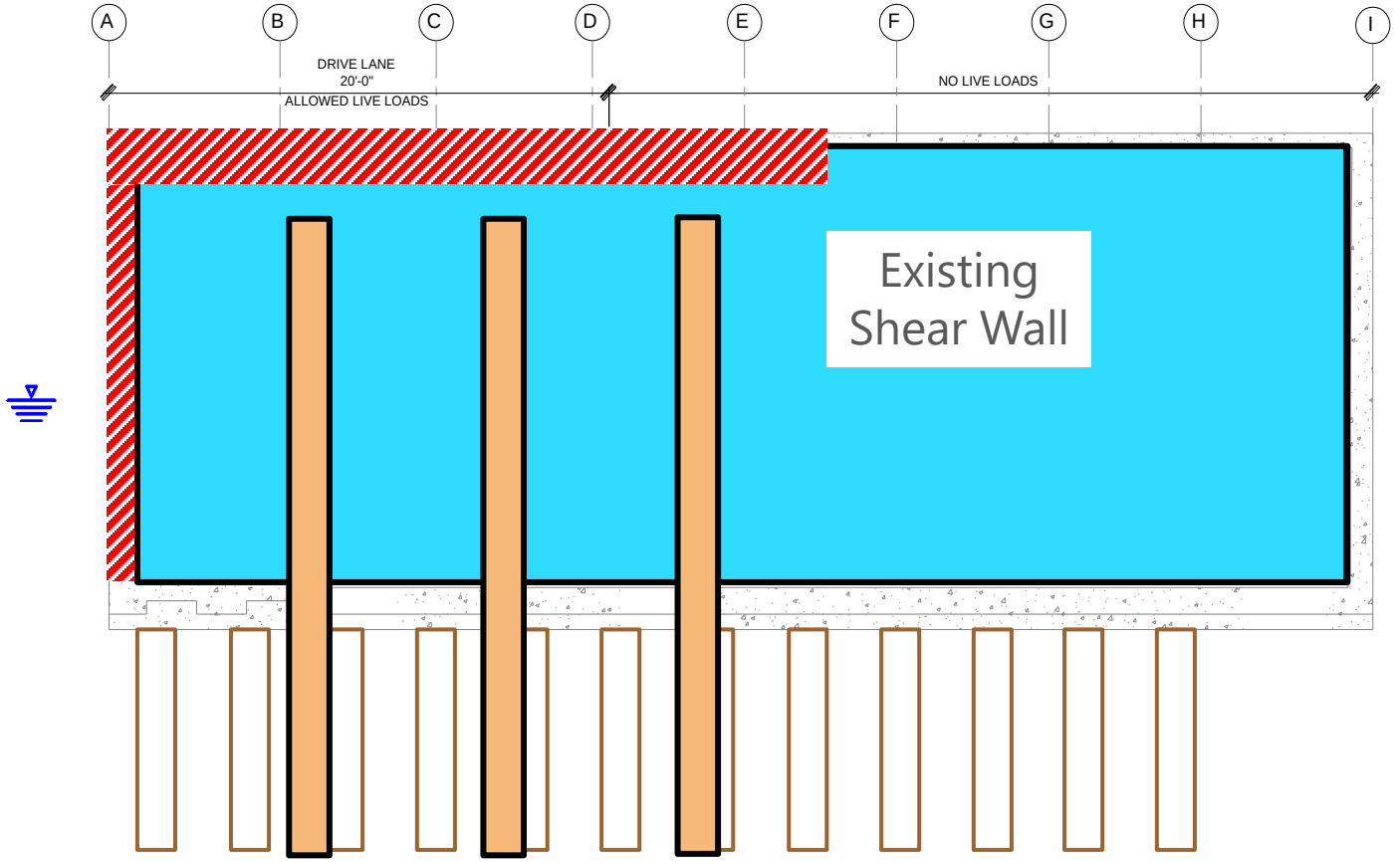
Concept – Step 1

- New drilled shafts installed into existing slope line
- Steel plates to cover pier holes



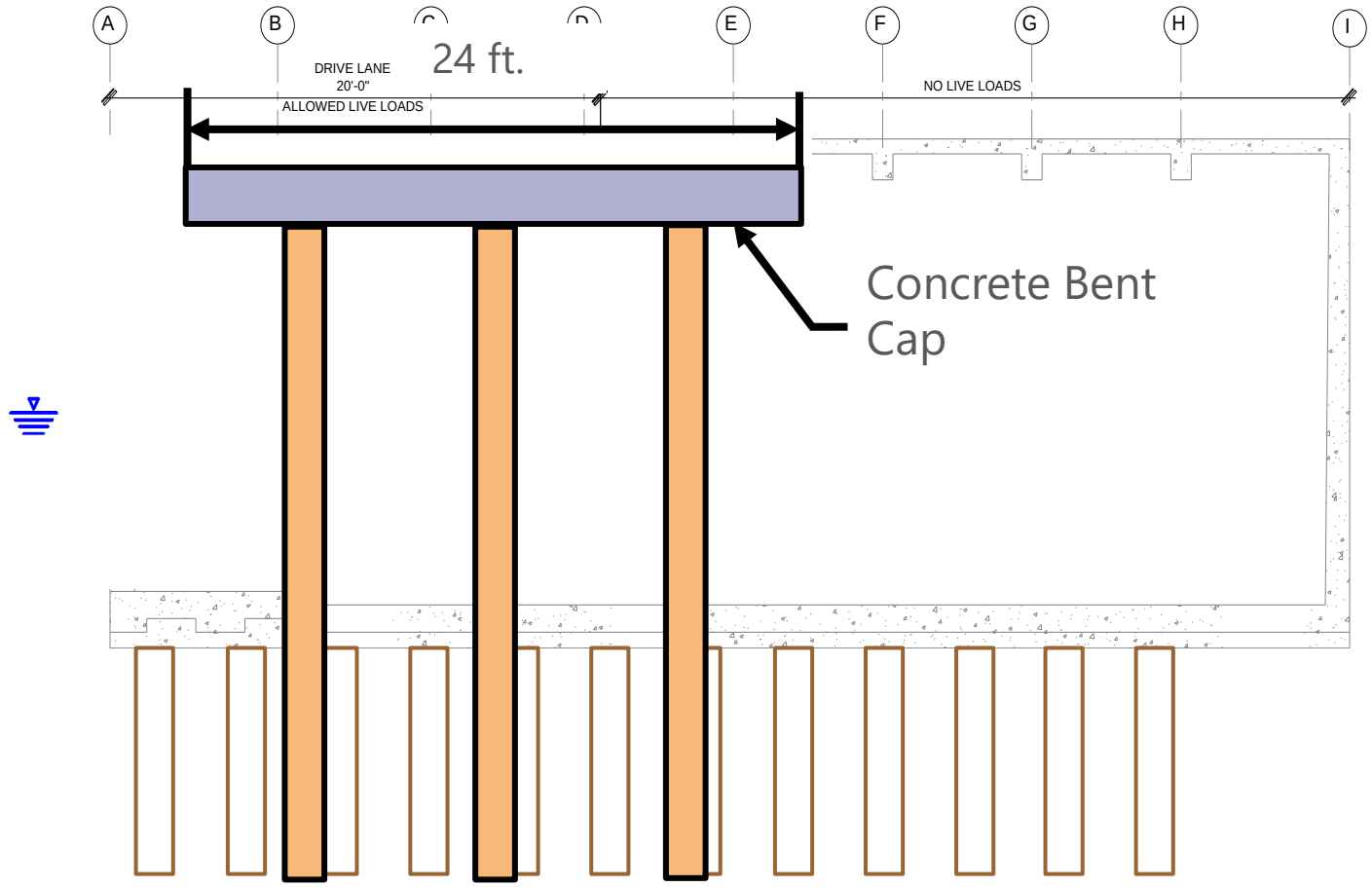
Concept – Step 2

- Demolish existing shear walls
- Demolish existing wharf deck



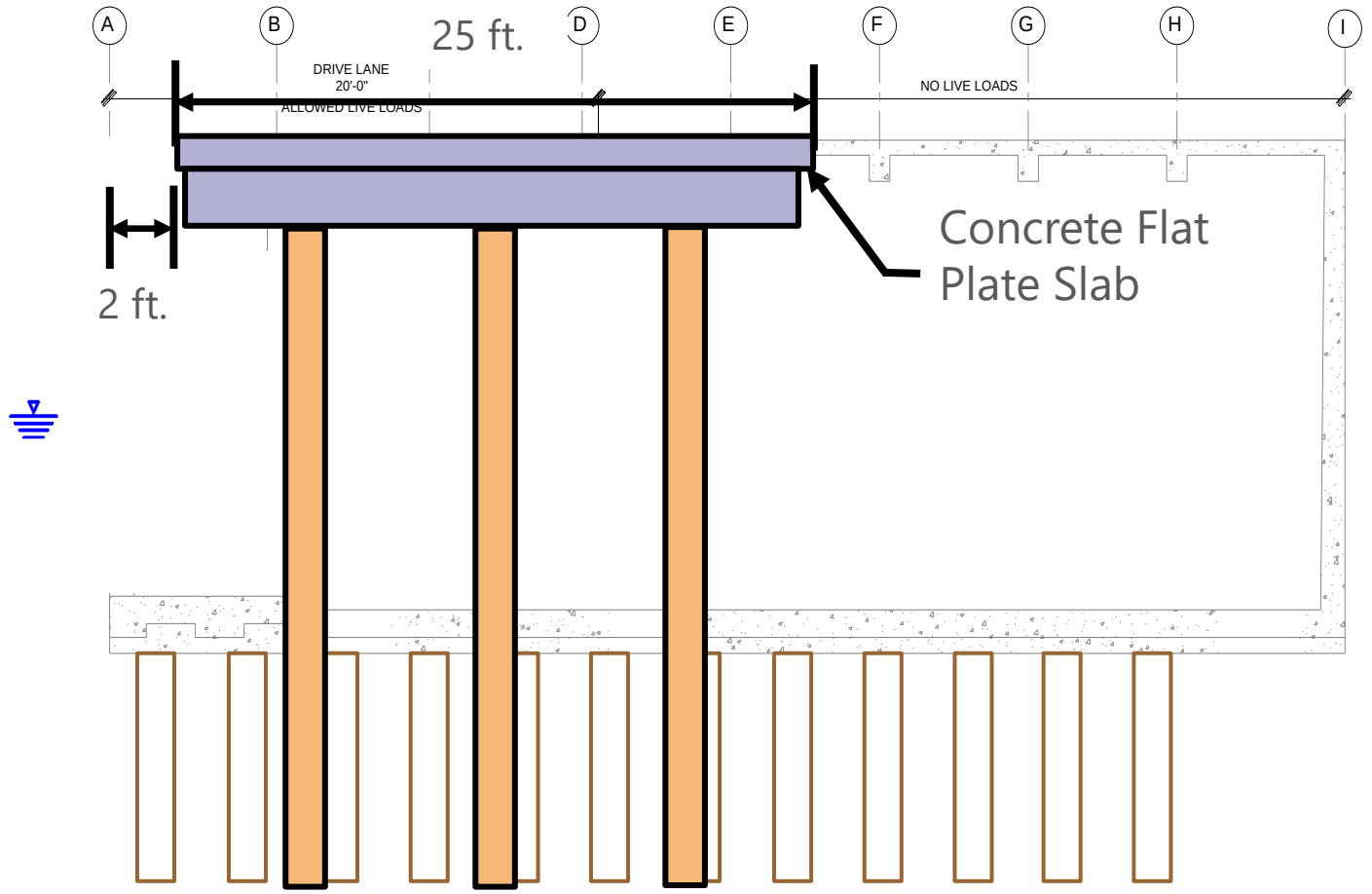
Concept – Step 3

- Install new cast-in-place bent cap



Concept – Step 4

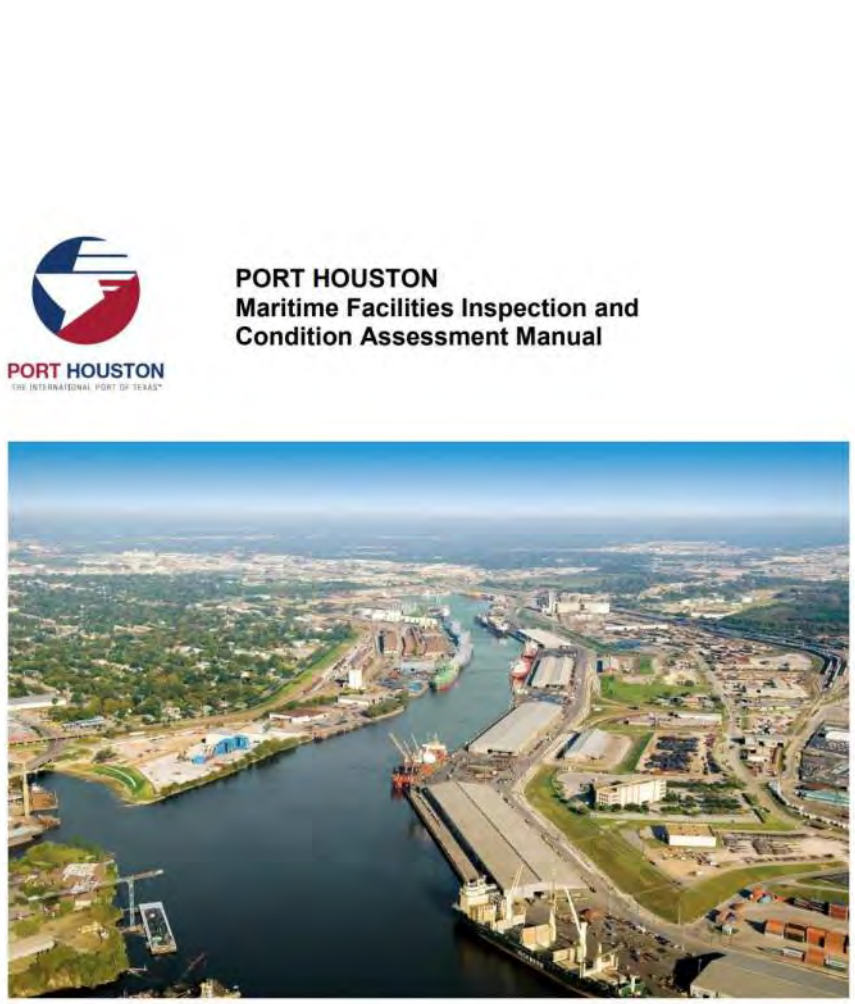
- Install new cast-in-place deck slab

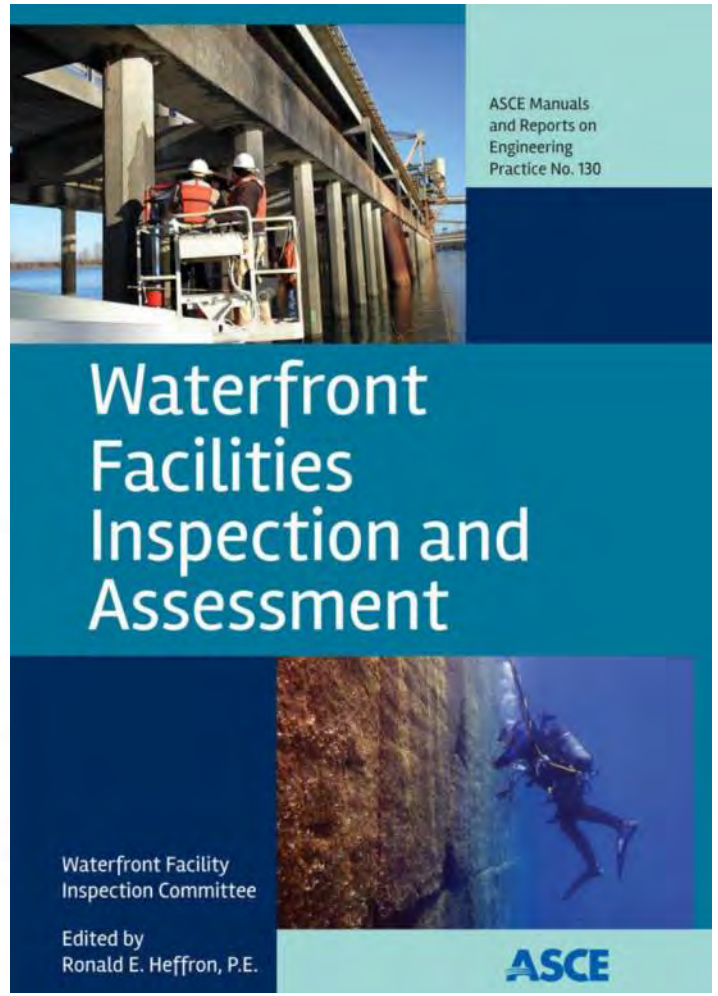


Beyond the Routine:
Closing Remarks

Summary

- Routine inspection is a critical part of an asset management program
  - ASCE 130
  - Port-specific plans
- Generally visual
- Provides general indication of current condition





Summary

- Asset management decisions often require more information
  - What is the remaining service life?
  - Is the structure safe in its current condition?
  - Can it be left as-is, and if so, for how long?
- In-depth or special field investigations and engineering analyses can help answer those questions
  - Corrosion assessment
  - Fatigue assessment
  - Instrumentation and monitoring
  - Specialized dynamic testing

Questions?

Jeff West, PhD, PE
Associate Principal
WJE Austin
jwest@wje.com

Jeremiah Fasl, PhD, PE
Associate Principal
WJE Austin
jfasl@wje.com