Post-Tensioning Inspection and Rehabilitation of the I-526 Wando River Bridge

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HDR

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Learning Objectives

At the end of this presentation, you will be able to…

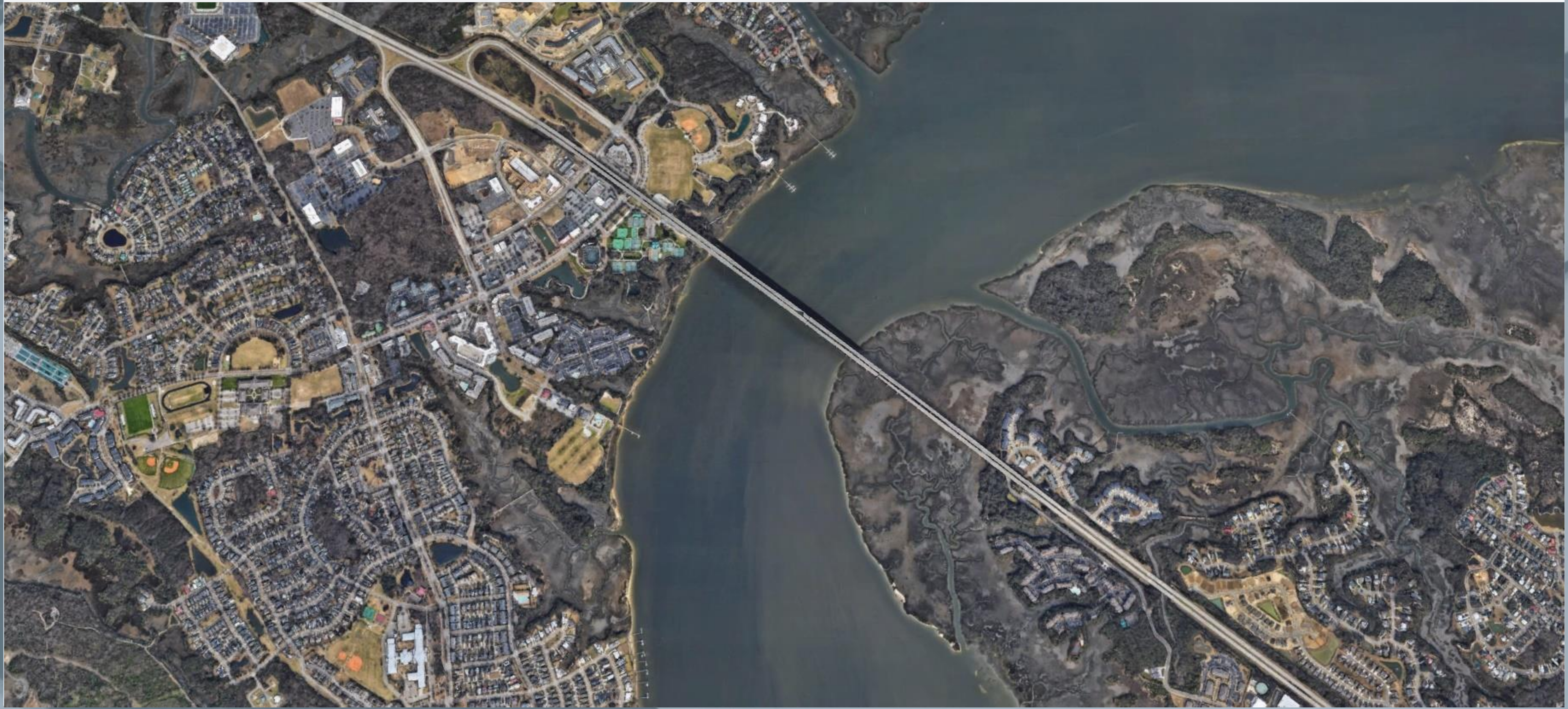
- Describe some NDE methods available for evaluating the condition of external tendons
- Describe the characteristics necessary to determine quality of tendon grout
- Describe a technique for supplementing external draped tendons
- Explain the importance of incorporating replaceable tendon details

Topics

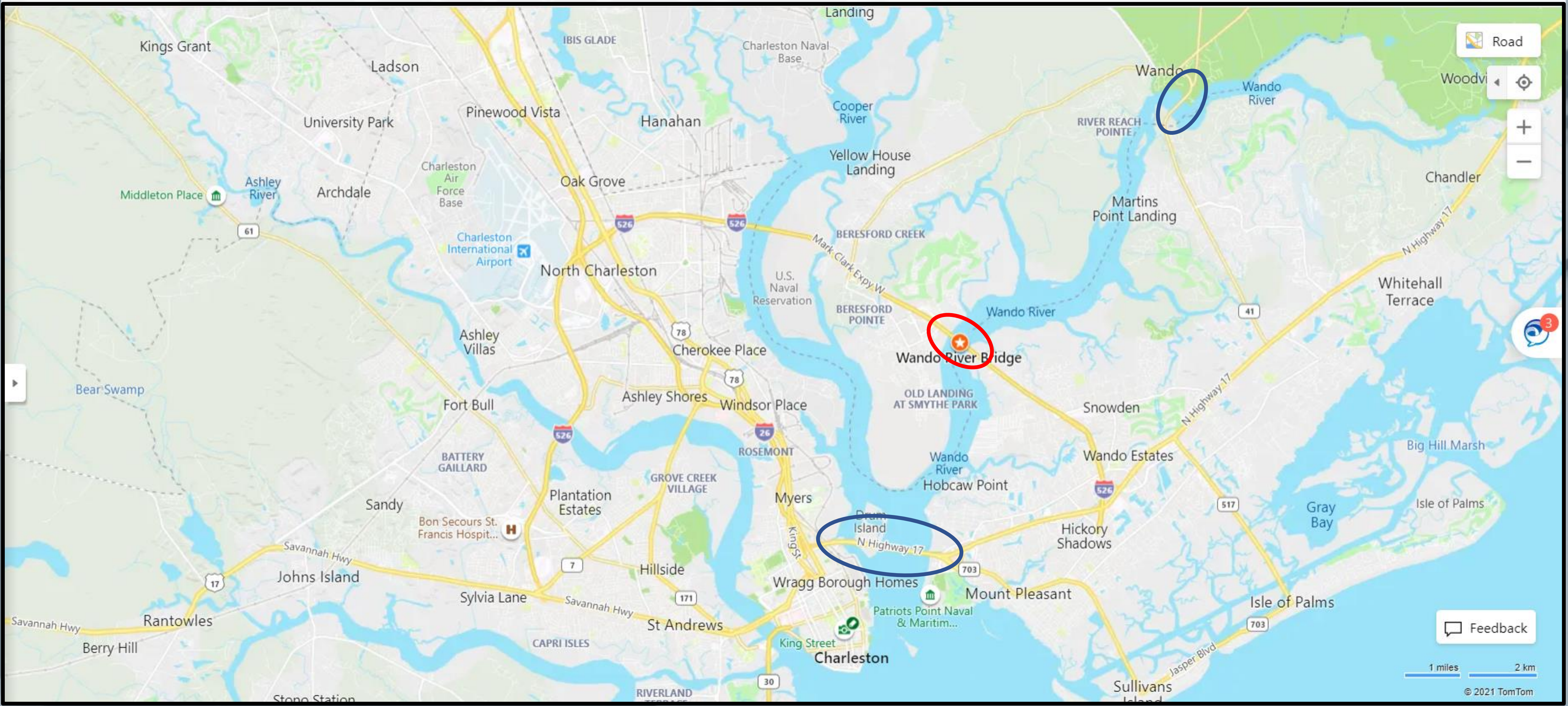
- Structure Overview
- Assessment Phase
- Remediation and Repairs
- Summary

Structure Overview

Structure Overview



Structure Overview



Structure Overview

ADT: 35,850 (Each Structure)
ADTT: 8,960 (Each Structure)

Of the three crossings, Wando carries:

- 39% of the total traffic
- 87% of the truck traffic

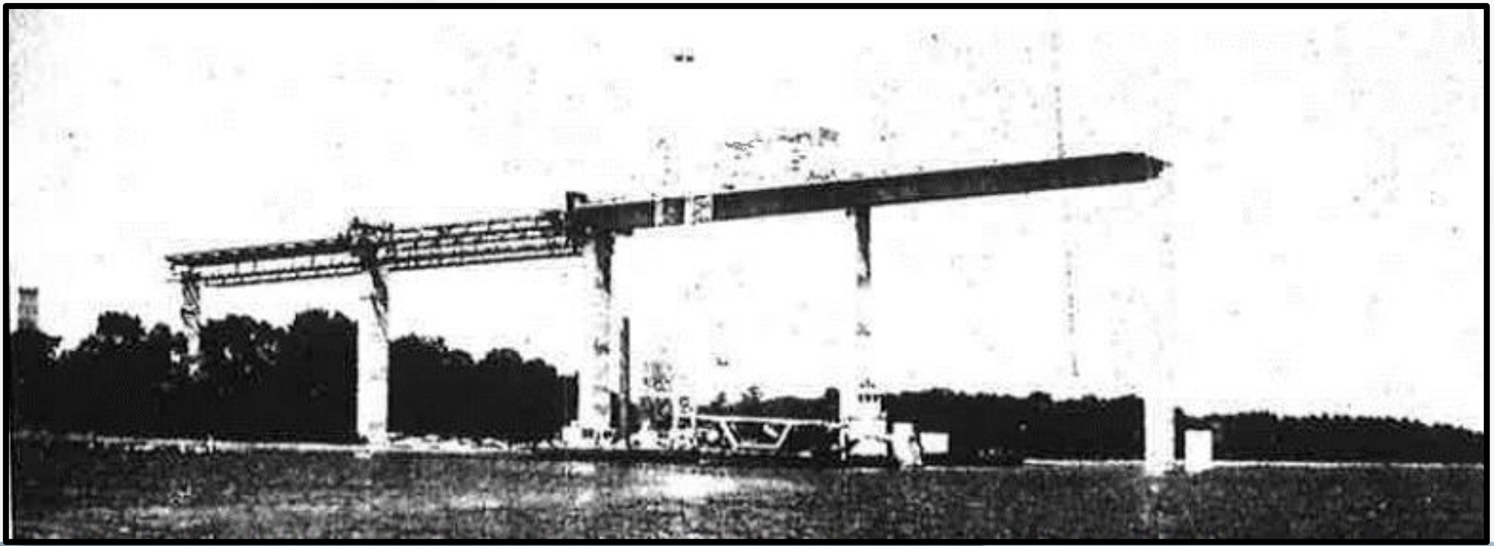
Structure Overview

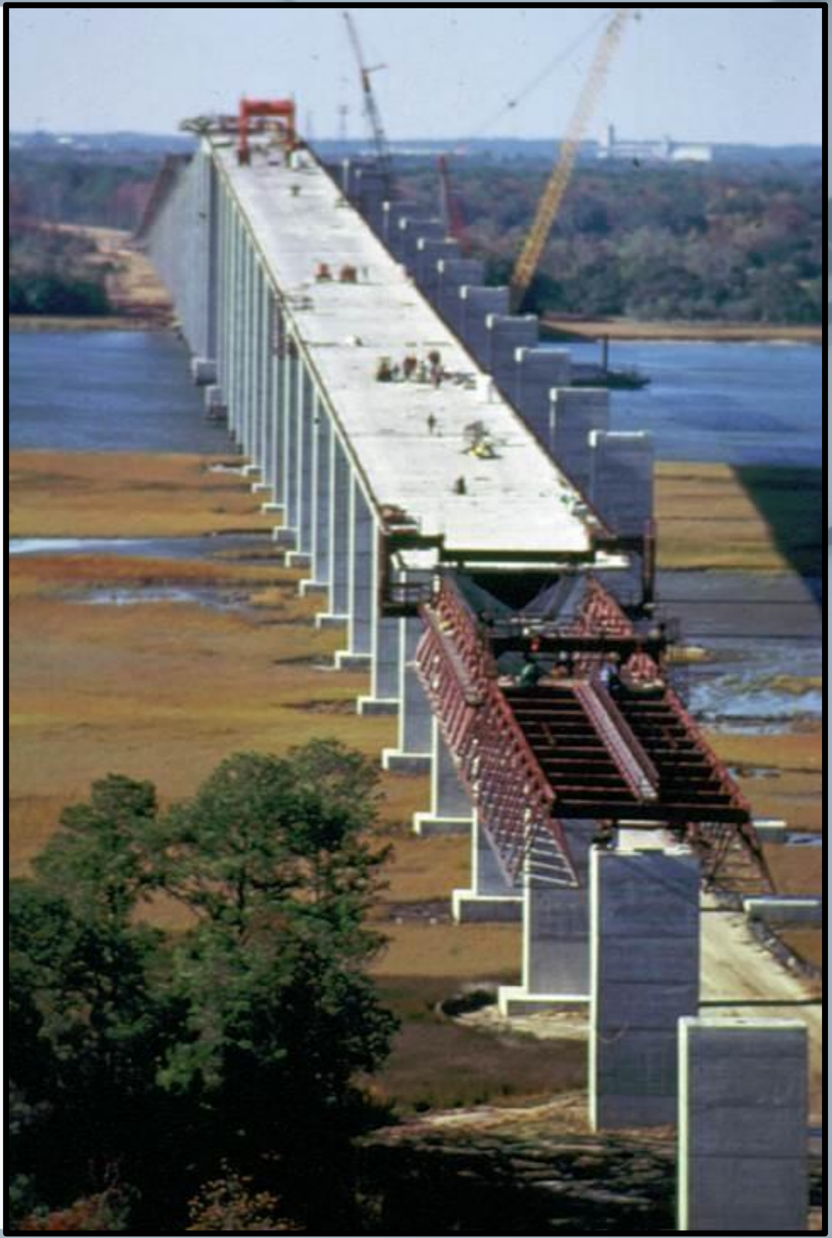
Erected: 1989
Opened: 1991
Construction cost: $32M

Total Length: 7,900ft (Each)
Max Span Lengths: 400ft
Approach Span Lengths: 150ft
Total Number of Spans: 49 (Each)

Structure Overview

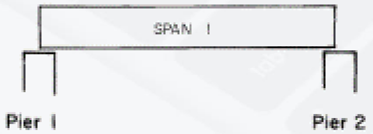
- Precast, Post-Tensioned Segmental Construction
- Approach Spans erected with the Span-by-Span Method
- Main Spans erected with the Balanced Cantilever Method utilizing a temporary piers
- Combination of Internal and External Tendons
  - 600 External Draped Longitudinal Tendons
  - 792 Internal Longitudinal Tendons

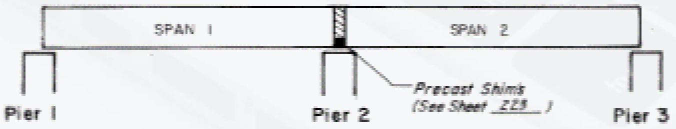


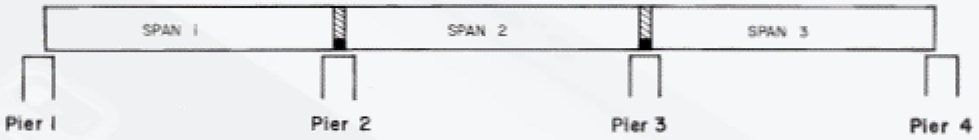


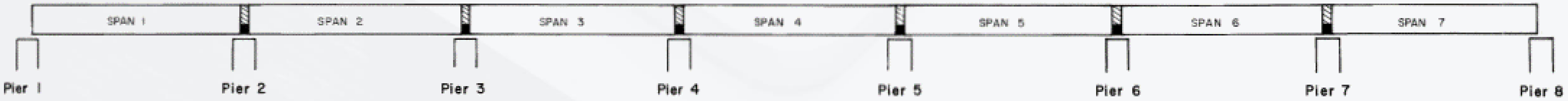
Structure Overview

- Approach Span Erection







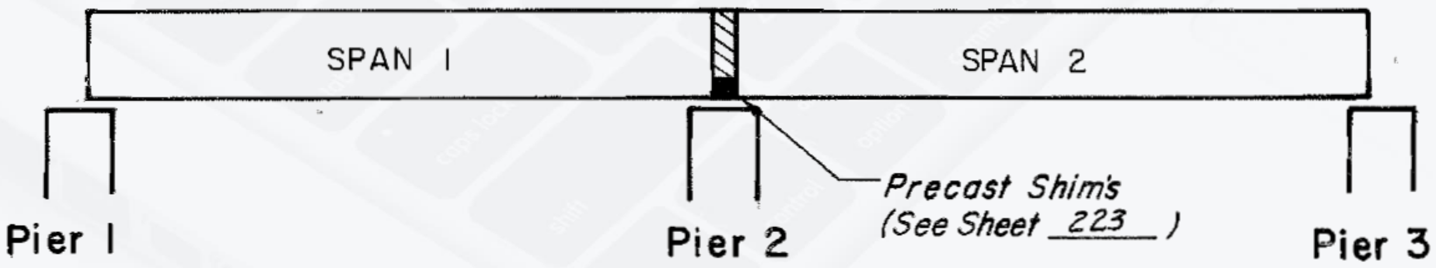


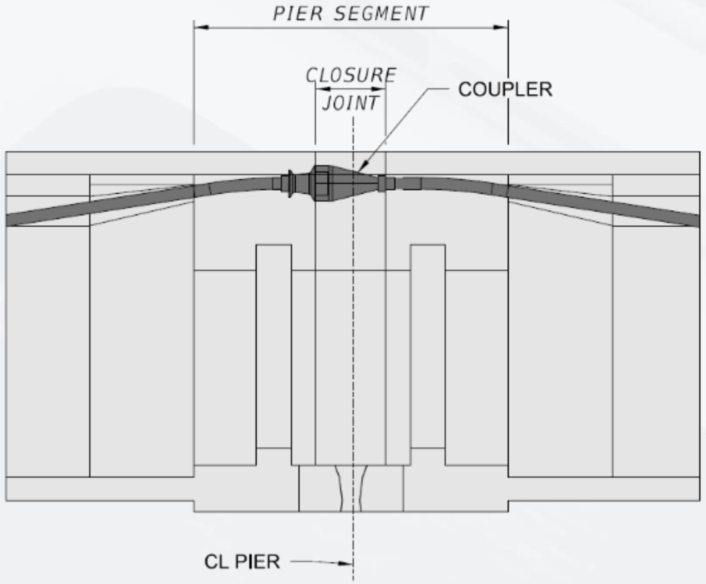
Structure Overview

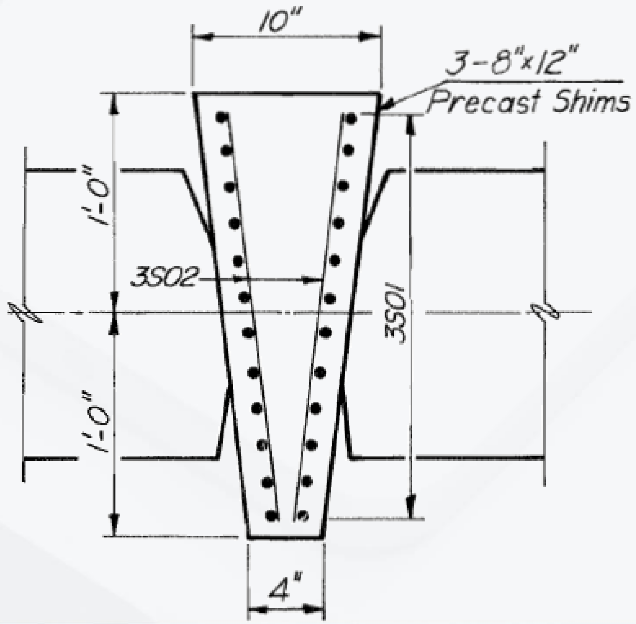
- Approach Span Erection

Structure Overview

- Approach Span Erection

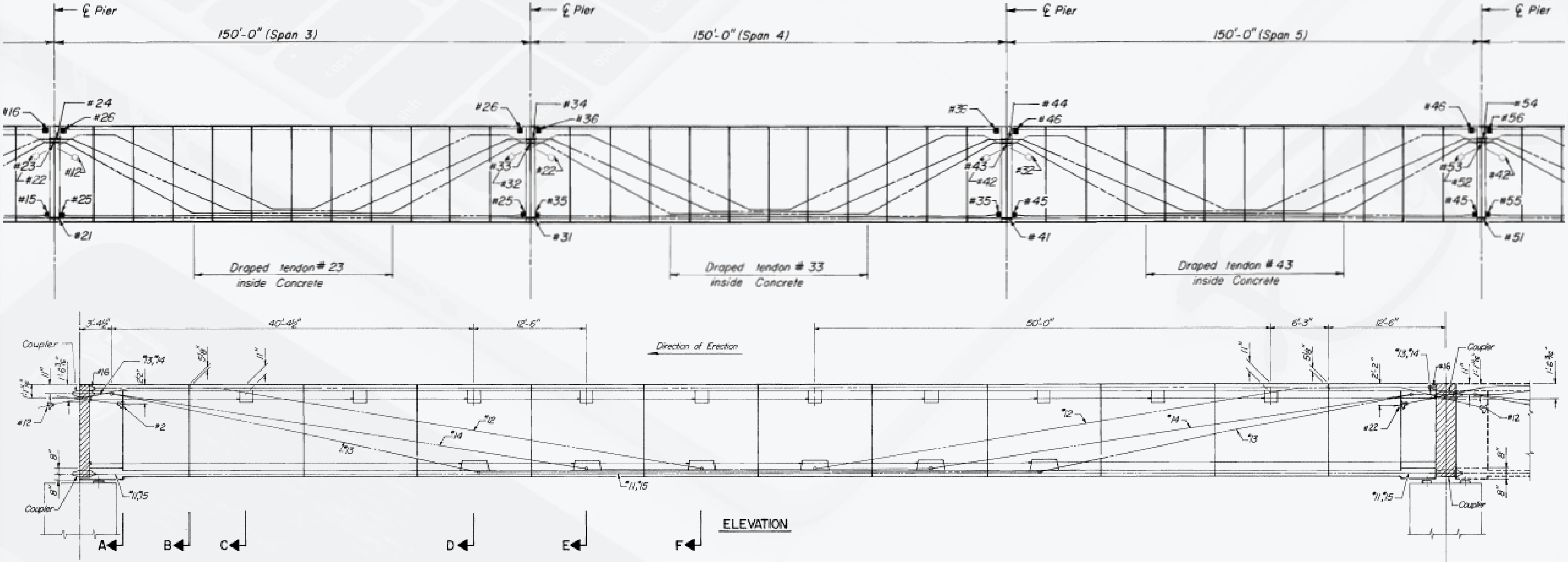






Structure Overview

- Approach Span Erection



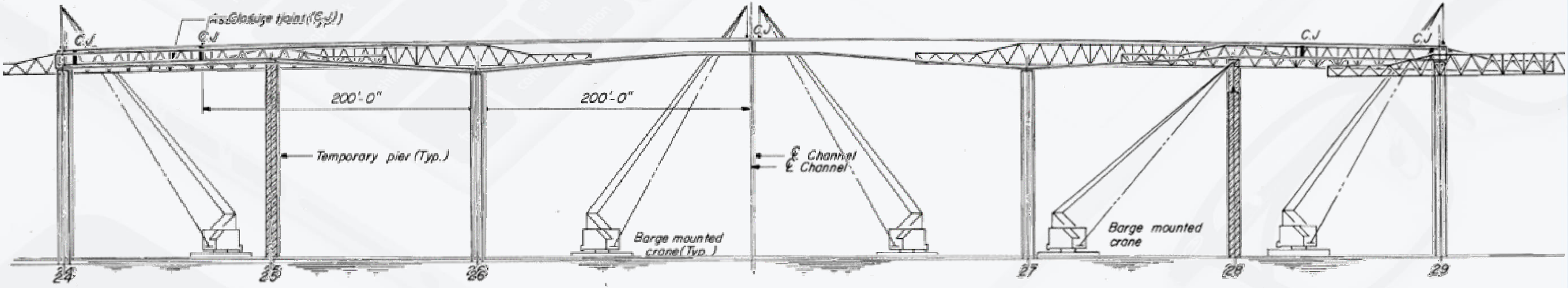
Structure Overview

- Approach Span Erection

- All original anchors except one per web are uninspectable and unreplaceable.
- The tendon with the accessible anchor deviates into the top slab for multiple segments, including over the pier segment, preventing its replacement.
- No accommodation for future tendons

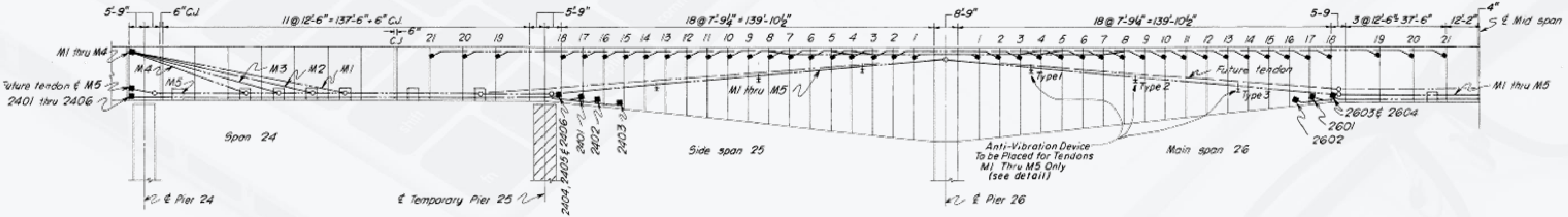
Structure Overview

- Main Span Unit Erection

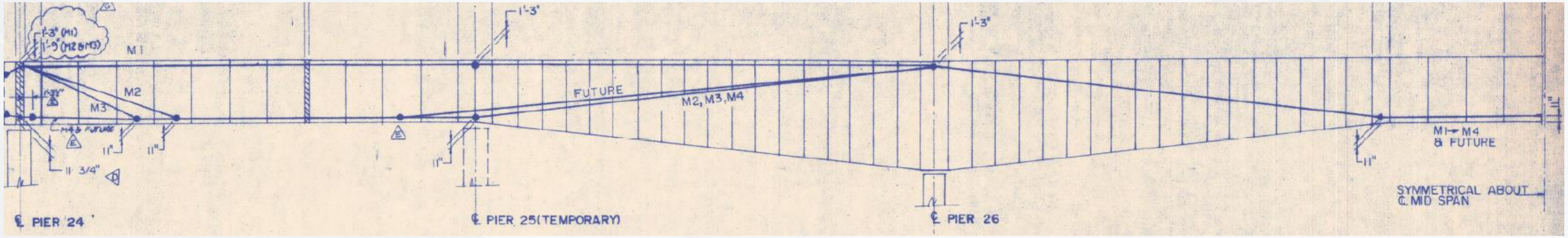


Structure Overview

- Main Span Unit Erection



Main Span Tendons in Contract Drawings

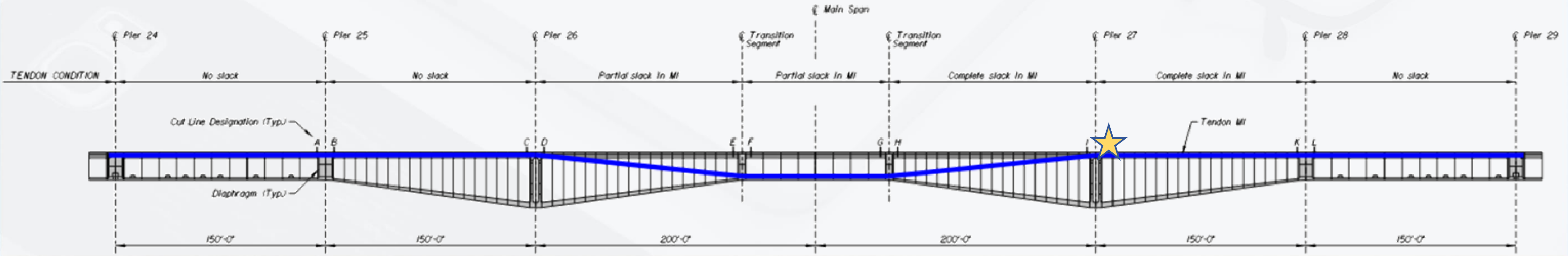


External Main Span Tendons in Shop Drawings

Structure Overview

Structure Overview

- M1 Tendon Failure
  - 19 Strand Tendon
  - 1,010 ft long
  - External Tendon
  - Continuous between Piers 24-29
  - Passing 8 Diaphragms



Structure Overview

- Response:
  - No other distress evident
  - Installed crack monitors at key locations
  - Closed one traffic lane to reduce load and provide a work zone on the deck
  - Modeled and analyzed main span unit
  - Installed one supplemental tendon
  - Detensioned and replaced M1 tendon

Assessment Phase

Assessment Phase

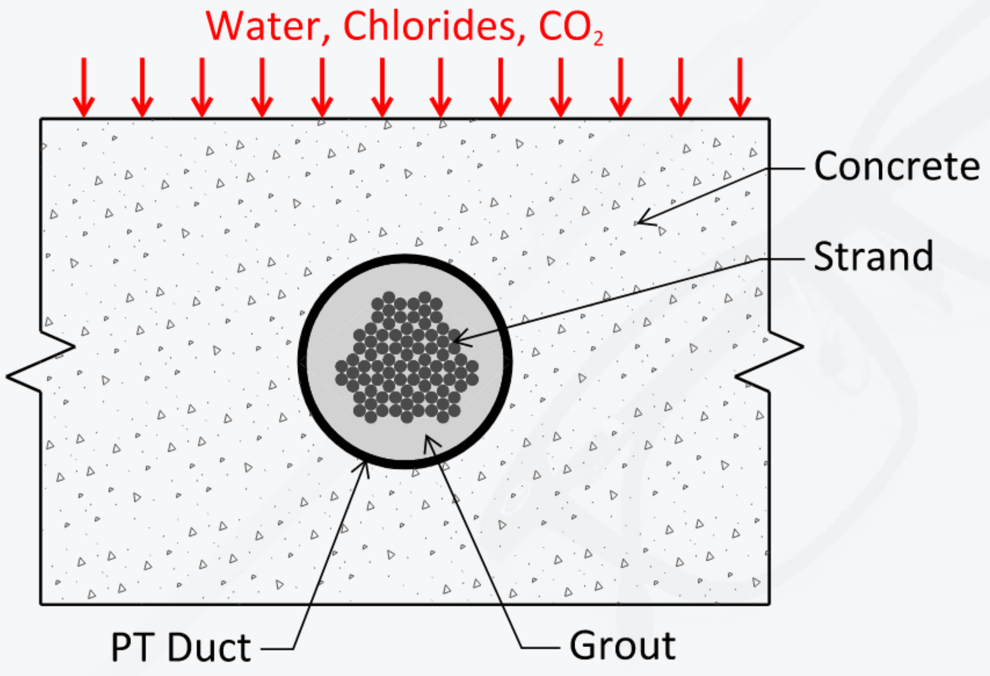
Limited Inspection, Testing, and Analysis Program

- Determine if grout deficiencies were present
- Determine the extent and significance of these deficiencies
- Identify sources and extent of corrosion in the external tendons
- Propose courses of remedial action

Assessment Phase

Tendon Protection

- Levels of tendon protection:
  - Structure
  - Duct
  - Grout
- Physical barrier to water and oxygen
- High pH grout forms a protective oxide film on the strand



Assessment Phase

Deficiencies to look for

- Physical deficiencies
  - Cracks, spalls, voids
  - Segmented, unsealed ducts
  - Cracked or punctured ducts
  - Unprotected grout ports
- Physical grout deficiencies
  - Soft grout
  - Segregated grout
  - Voids and poor grout cover
  - Microcracking
- Chemical deficiencies
  - Carbonation
  - High chloride content
  - High sulfate content

Assessment Phase

Program included:

- M1 Tendon Investigation
- Visual tendon and structure inspections
  - Borescope inspections of anchors and high points
- Magnetic flux testing
- Capacitive probe inspection
- Grout testing
- FE Modeling / Load Rating

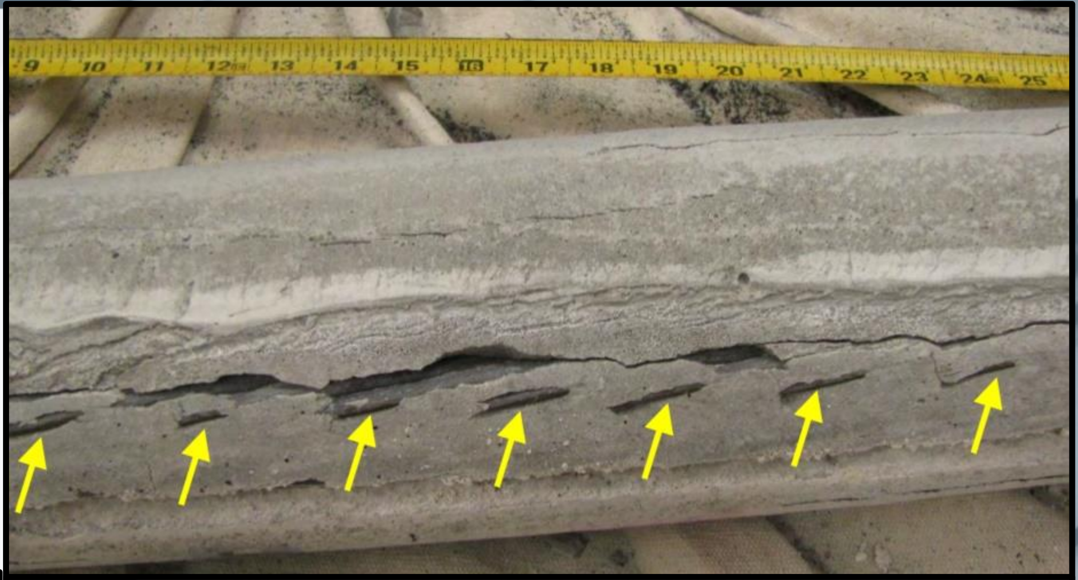
Assessment Phase

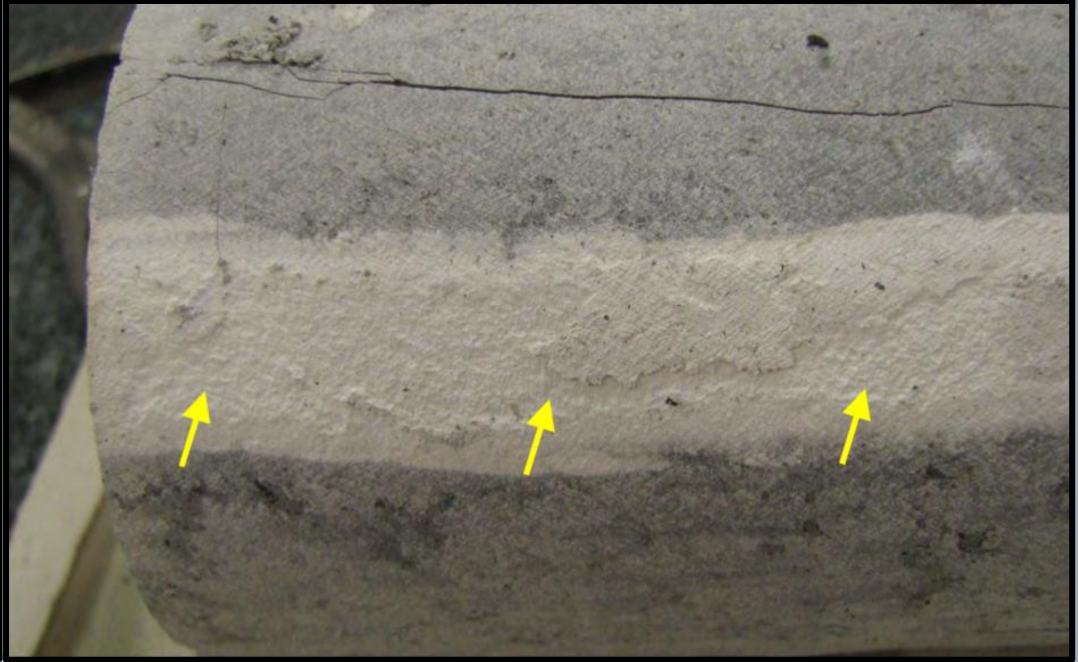
M1 Investigation

Assessment Phase

M1 Investigation

- Tendon and Grout condition observations





Assessment Phase

M1 Investigation

- Grout condition observations
- Corrosion potential (ASTM C876)
  - Indicated no active corrosion for all tendon samples

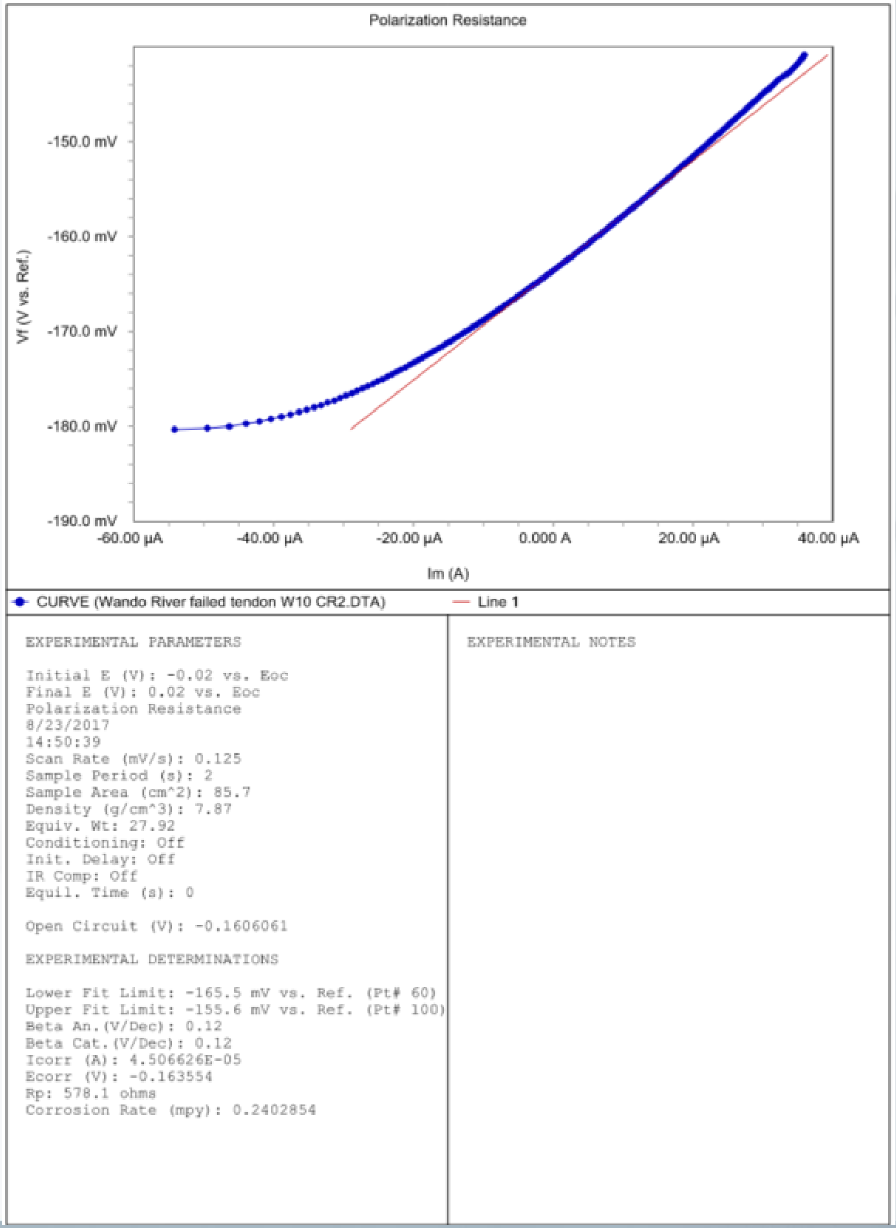
Assessment Phase

M1 Investigation

- Grout condition observations
- Corrosion potential
- Corrosion rate
  - Linear polarization resistance test
  - Results were very low
    0.04 mpy - 0.24 mpy

$$I_{corr} = \frac{\beta_a \cdot \beta_c}{2.3 \cdot R_p \cdot (\beta_a + \beta_c)}$$

$$CR = \frac{I_{corr} \cdot k \cdot EW}{d \cdot A}$$



Assessment Phase

M1 Investigation

- Grout condition observations
- Corrosion potential
- Corrosion rate
- Grout tests
  - Grout alkalinity (pH)
  - Chloride content (AASHTO T-260)
  - Sulfate content (ASTM C114)
  - Moisture content (ASTM C566)
  - Petrographic analysis

Assessment Phase

M1 Investigation

- Grout condition observations
- Corrosion potential
- Corrosion rate
- Grout tests
- Tensile strength testing (ASTM A1061)
- Duct material tests (ASTM D3350, PTI/ASBI M50.3)

Assessment Phase

M1 Investigation

- Grout condition observations
- Corrosion potential
- Corrosion rate
- Grout tests
- Tensile strength testing (ASTM A1061)
- Duct material tests
- Summary

Away from rupture location

- Strand was in good condition with very little corrosion since construction
- Corrosion potential showed low probability of active corrosion
- Measured corrosion rates were low
- Grout: high pH, low chlorides, normal sulfates, normal moisture content, but with high entrapped air voids and grout fracture
- In short: no significant corrosion would be expected if encased in grout

Assessment Phase

M1 Investigation

- Grout condition observations
- Corrosion potential
- Corrosion rate
- Grout tests
- Tensile strength testing (ASTM A1061)
- Duct material tests
- Summary

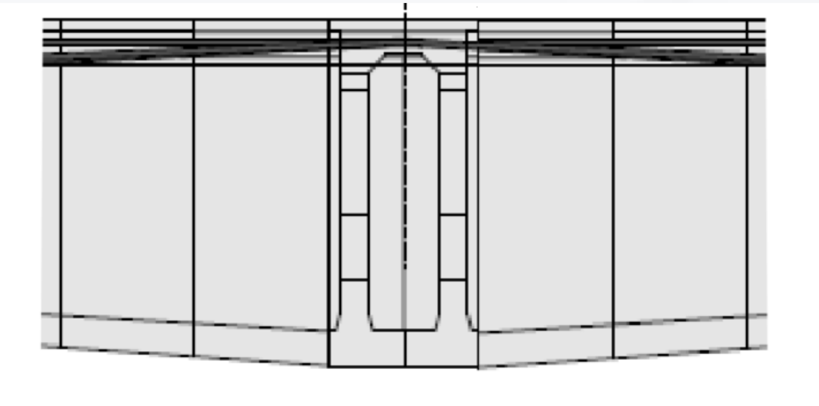
At the rupture location

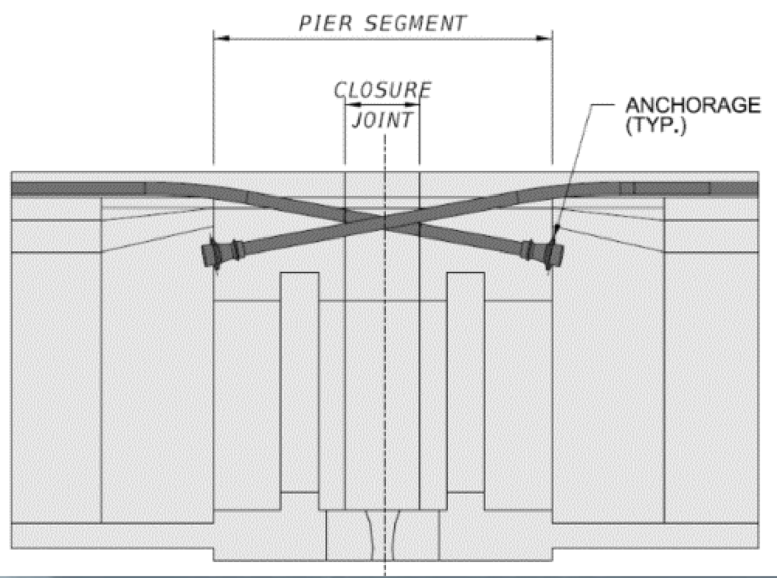
- Severe corrosion of the strand
- Duct was approximately 80% empty
- pH was very low
- Water infiltration
- In short: large void at the high point of the tendon left the strand unprotected

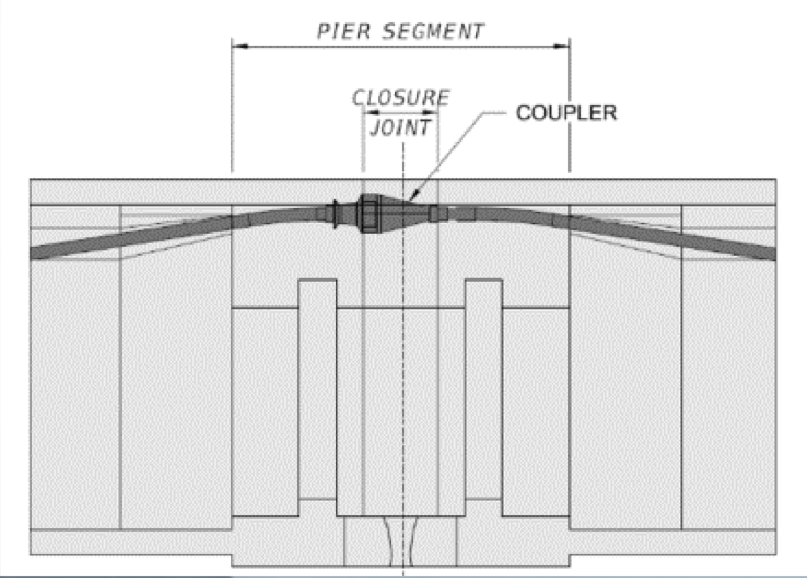
Assessment Phase

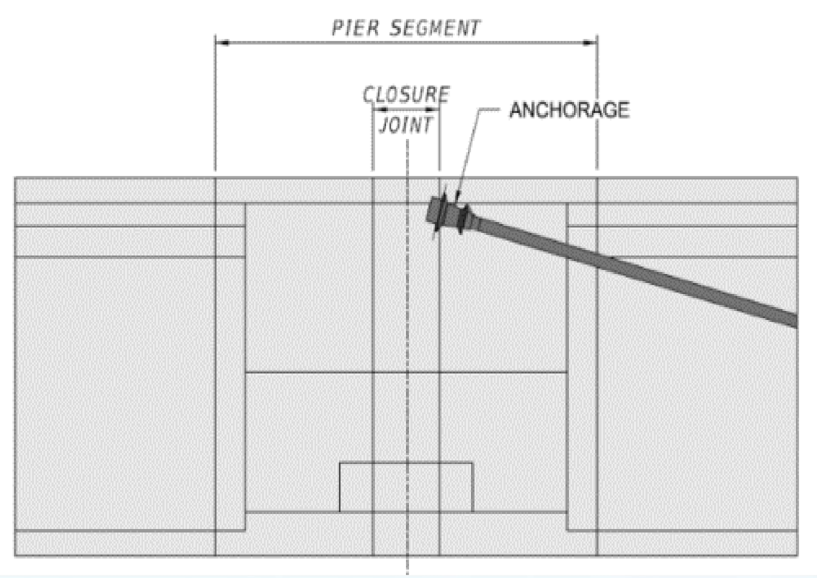
Visual Tendon and Structure Inspections

- Walk-through inspection of both structures
- Borescope inspections of anchors and high points





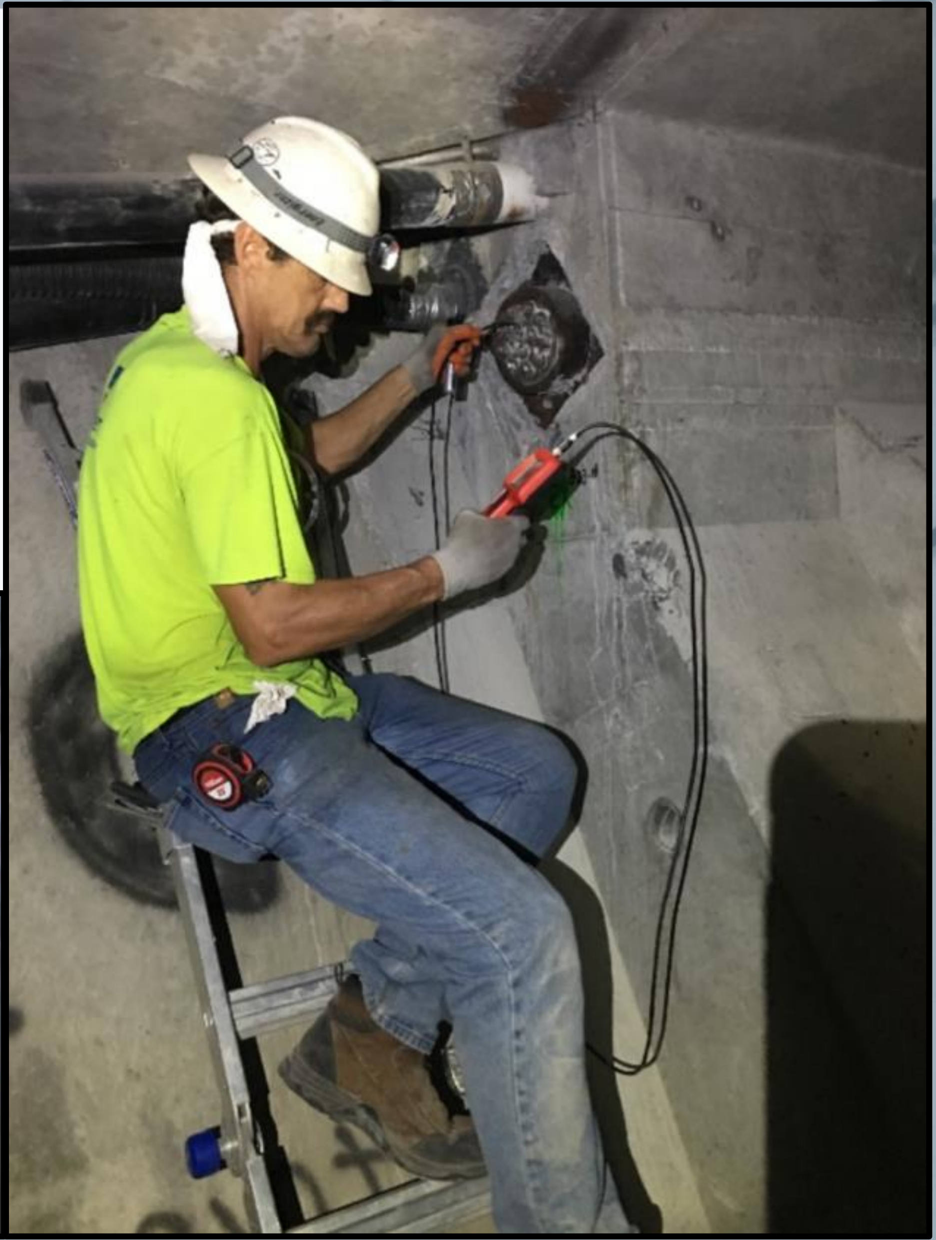




Assessment Phase

Visual Tendon and Structure Inspections

- Total of 300 borescope inspections performed
  - 270 Accessible external tendon anchors investigated
  - 30 External tendon high points investigated
- Various deficiencies included
  - Grout voids
  - Exposed strand
  - Corrosion
  - Soft grout
  - Water leaking



Assessment Phase

Visual Tendon and Structure Inspections

- Leaking segment joints
- Slack tendon (Span 16)
  - No evidence of water infiltration, corrosion, or poor grout
- Slack strands
  - Fully grouted in place, indicating occurrence during construction

Assessment Phase

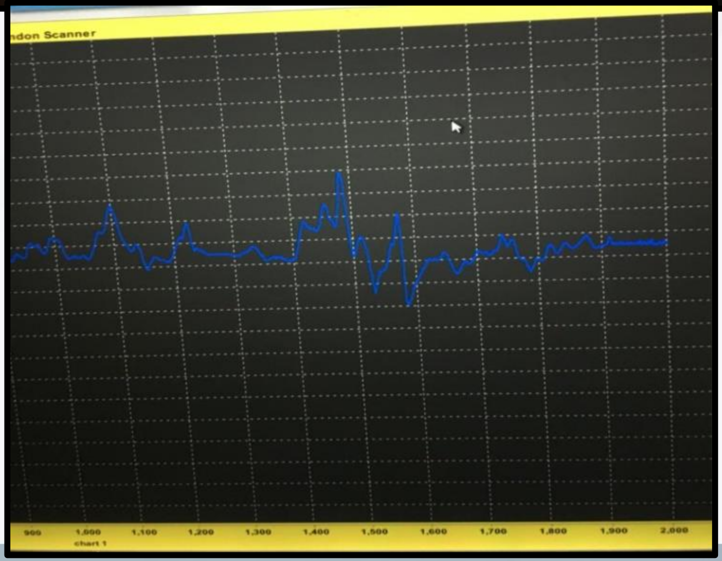
Magnetic Flux Testing

- Locates areas of steel section loss due to corrosion, wire pitting, or breakage
- Applies a magnetic field to induce flux paths between the poles
- Magnetic field "leaks" at points of section loss and the change is detected by sensors
- Changes are correlated to section loss based on previous calibrations
- Magnet and sensors on a wheeled frame that is moved along the tendon free-length
- Data is reported in real time to the operator

Assessment Phase

Magnetic Flux Testing

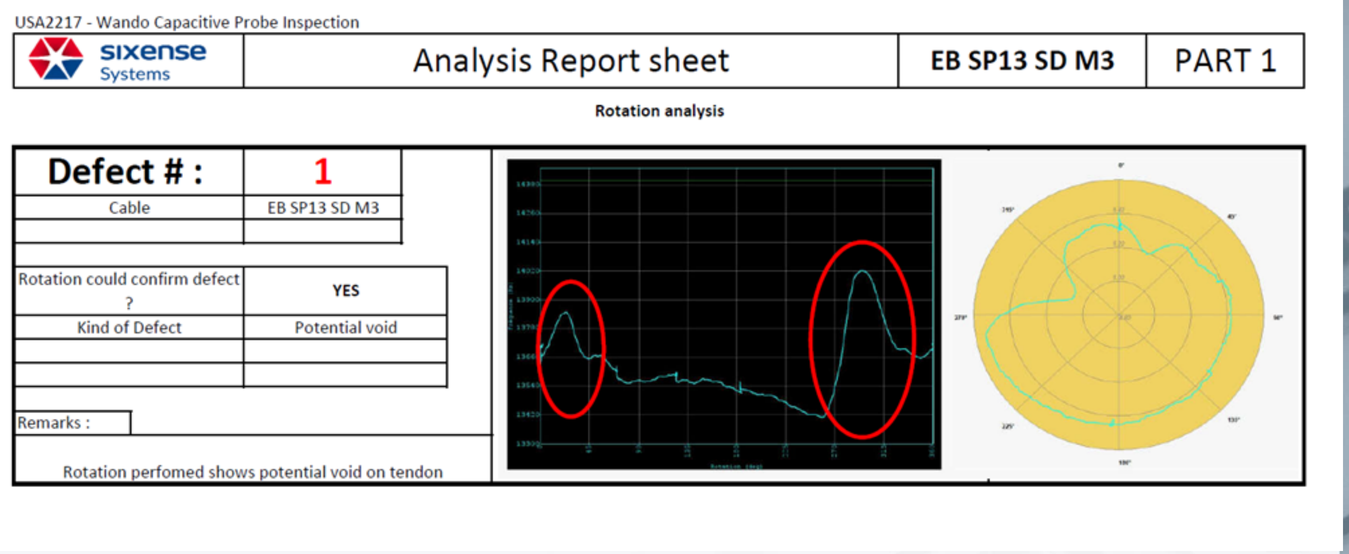
- Total of 24,525 lf of external tendons were investigated
- Locations of indicated section loss were flagged for monitoring or opening for investigation
- Openings at the five tendons in the highest category revealed minor corrosion that did not warrant further testing or replacement



Assessment Phase

Capacitive Probe Inspection

- Locates defects including presence of voids, water, white paste, and soft grout
- Monitors the capacitance between two electrodes
- Contrast in permittivity between different materials and moisture content allows measurement of capacitance variation.
- Inspection depth of 30mm
- Moved along duct until a defect is located and rotated around duct to check full section at the point of interest
- Limitations:
    - Requires HDPE ducts with cementitious grout
    - Metallic surfaces within 30cm can interfere and alter the measured frequencies
    - Space required for rotations is 30cm; cannot inspect tendons close to the webs


USA2217 - Wando Capacitive Probe Inspection

sixense Systems | Analysis Report sheet | EB SP13 SD M3 | PART 1

Rotation analysis

Defect # :	1
Cable	EB SP13 SD M3
Rotation could confirm defect ?	YES
Kind of Defect	Potential void

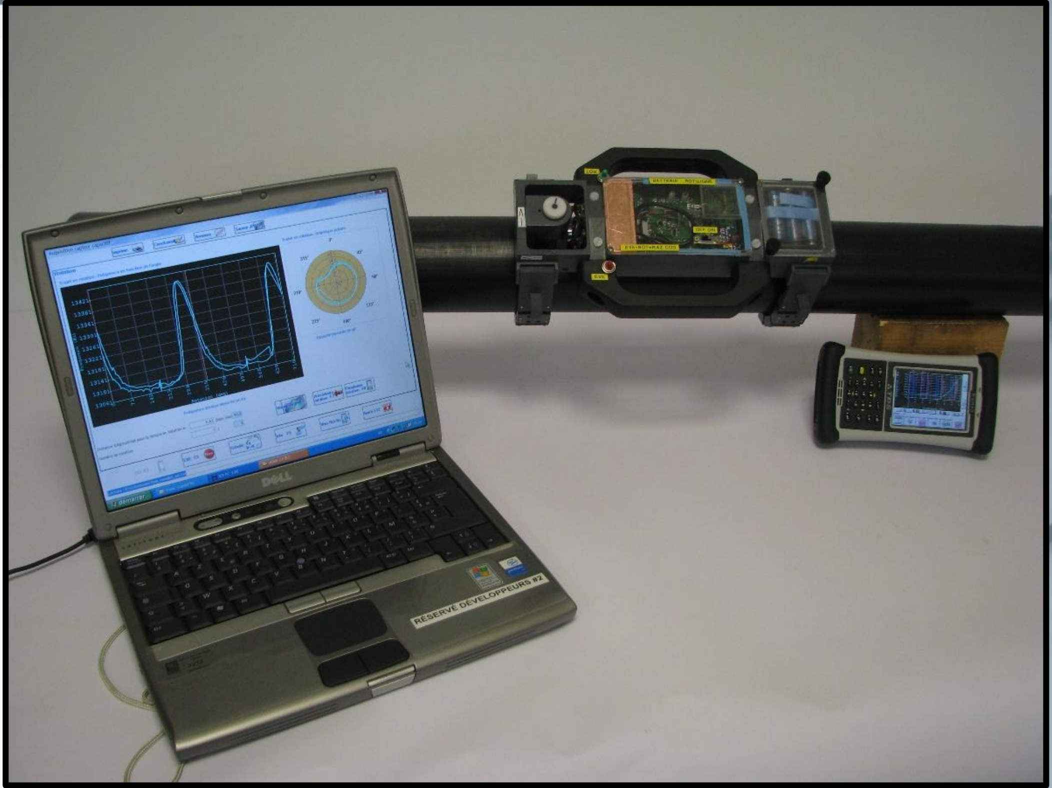
Remarks :

Rotation perfomed shows potential void on tendon

Assessment Phase

Capacitive Probe Inspection

- Performed 44,445 LF of tendon scanning between both structures



- Located voids of various size and severity
  - Some larger voids, similar to image
  - Some areas of heavily air-entrained grout
  - Small separations between the grout and to of duct
- No evidence of significant distress identified

Assessment Phase

Grout Testing

- In-situ testing
  - Corrosion potential
  - Corrosion rate
  - Grout alkalinity (pH)
- Laboratory testing
  - Chloride content
  - Sulfate content
  - Moisture content
  - Petrographic analysis

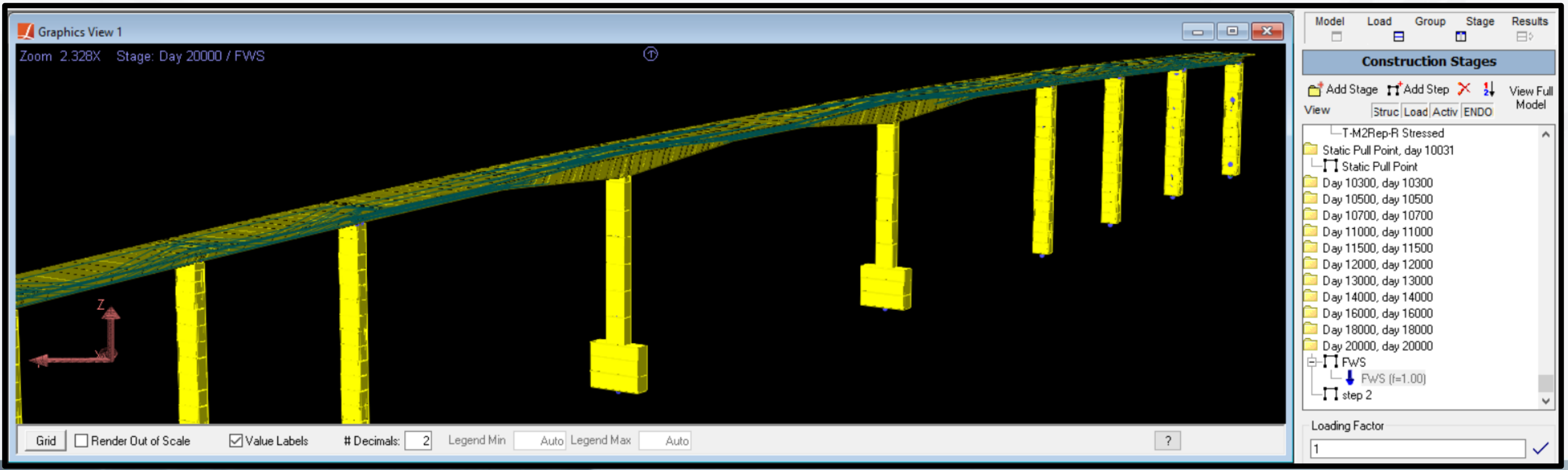
- Findings
  - Grout was predominantly good quality with a high pH
  - Moisture content was typically normal
    - a few locations were elevated, which could signify water infiltration
  - Chloride content was typically low
  - Sulfate content was low
  - No corrosion potentials indicated high probability for active corrosion
  - All corrosion rates measured low (<0.3 mpy)

No significant tendon corrosion is expected for tendons that are encased in grout

Assessment Phase

Modeling and Limited Load Rating

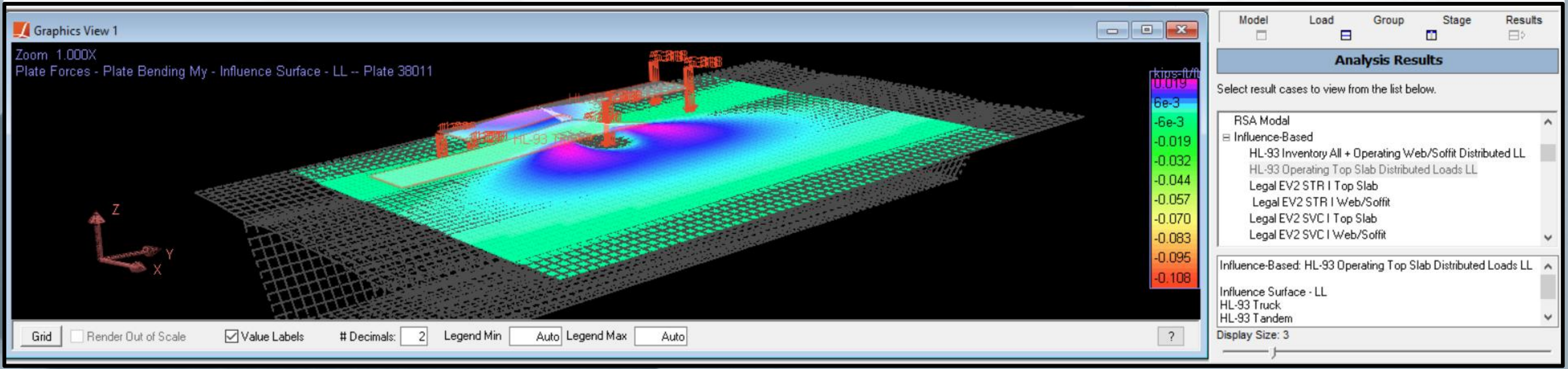
- Developed 3D Time-Dependent Staged Construction Models with LARSA 4D
  - Main Span Unit
  - Typical Approach Span Unit
  - Transverse Analysis Models
- Construction sequences based on contract plans, anchor configuration, and photos
- Developed calculations for service stresses, ultimate moment, and shear & torsion



Assessment Phase

Modeling and Limited Load Rating

- Evaluated the structures for
  - Original Design Code: AASHTO Standard Specifications, 1977
  - Current Design Code: AASHTO LRFD, 8th Edition
- All subsequent design and final load rating was performed with LRFD and LRFR
- Determined safety for continued service with various tendon loss “what-if” scenarios



Assessment Phase

Condition Summary

- M1 tendon failed due to the existence of a large grout void and water infiltration
- Grout throughout the structure was of reasonably good quality and would protect tendons as intended if fully encased
- Water infiltration was observed in several locations
- Several leaking segment joints
- One detensioned external tendon
- Use of couplers and embedding of anchors precludes direct replacement of most tendons

Remediation and Repairs

Remediation and Repairs

Main Span Supplemental Tendons

- Second WB tendon rupture, May 2018
- Rupture at same location as M1 tendon
- Closed WB structure; crossovers used to shift WB lanes to EB structure

Remediation and Repairs

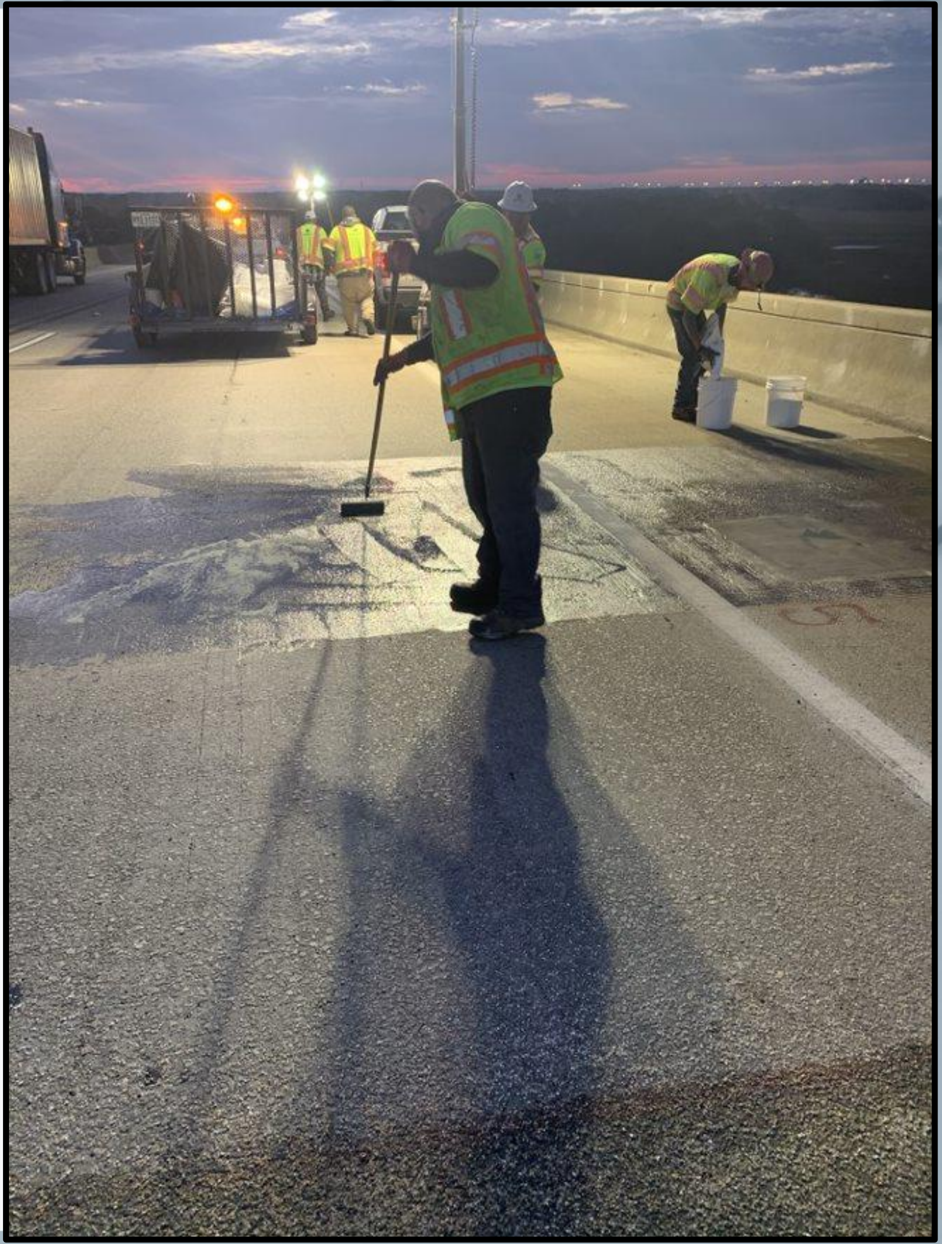
Main Span Supplemental Tendons

- Two supplemental tendons permanently installed in both structures
- Deck repairs performed
- Metallurgical testing
- Bridge reopened after 19 days

Remediation and Repairs

Stop the Water

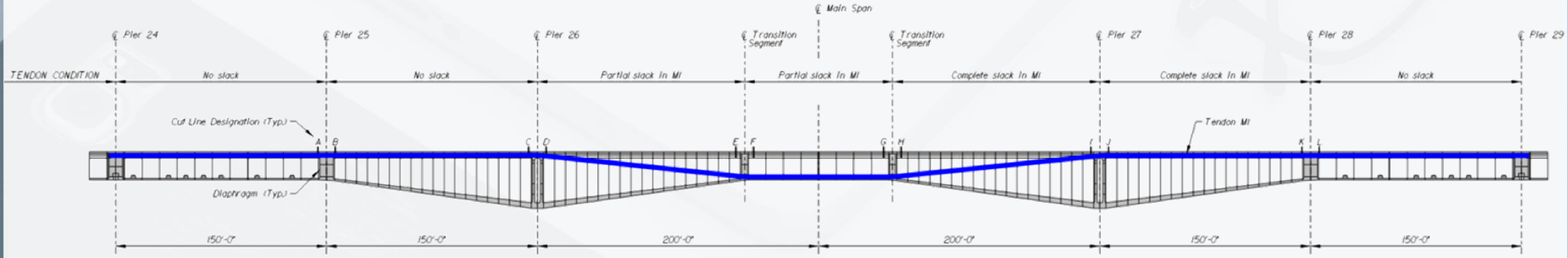
- Phase 1:
  - Locate and seal all exposed grout ports on the deck
    - Locations cored, sides roughened, cleaned, and filled with epoxy grout
  - Repaired deck spalls and delaminations
  - Sealed deck repairs, cracks, leaking segment joints and all closure pours with high molecular weight methacrylate (HMWM)
  - Extended limits of HMWM at select locations
- Phase 2:
  - Polyester polymer concrete (PPC) overlay
  - Scheduled Spring 2021



Remediation and Repairs

Replace M2 Tendons

- Advanced corrosion was identified on two additional tendons in the WB structure
- Detensioning required prior to replacement
  - Method used for M2s differed from previous rupture replacements
  - M2s were completely intact, but had partially corroded

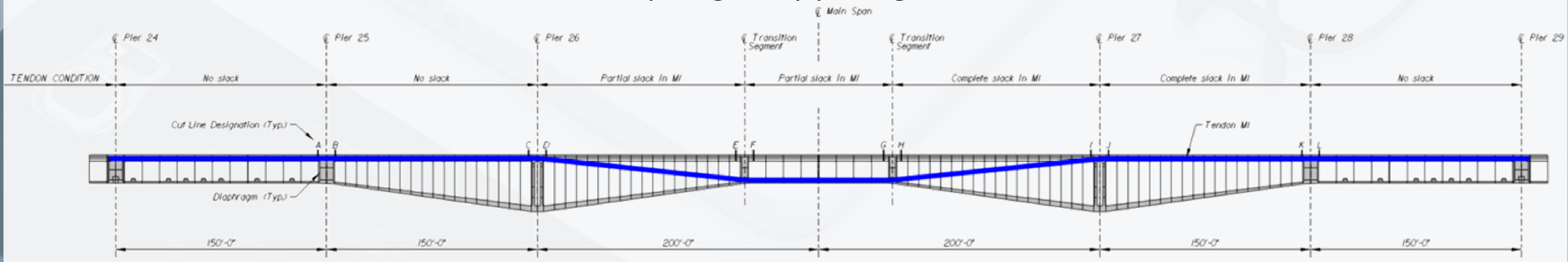


Detensioning Plan for Ruptured Tendons M1 and M4

Remediation and Repairs

Replace M2 Tendons

- Detensioning of ruptured M1 and M4 tendons
  - Install heavy duty clamps every 4ft along the full length of the tendon
  - Grout removed at specific locations on either side of diaphragms
  - Strands cut with powered cutoff saw alternately on either side of P25 to match broken strands at P27 and balance the tendon force.
  - Cut strands at P28 to match P27
  - Cut one strand at each point sequentially until all strands are cut
  - Remove the tendons from the diaphragms by pulling the tails

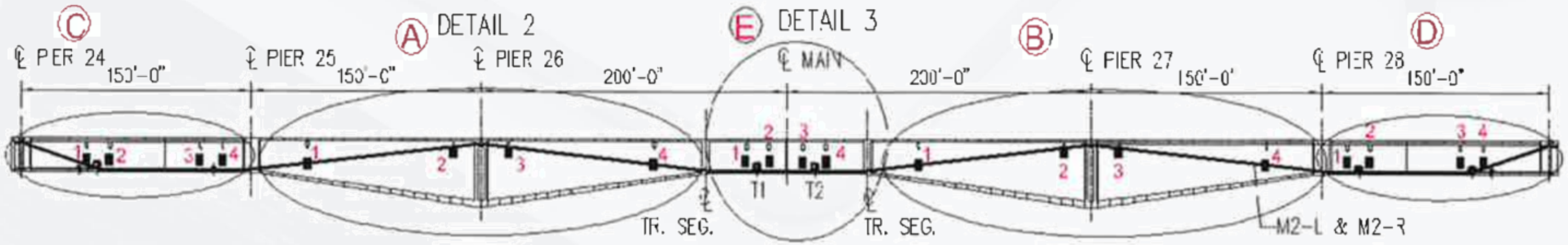


Detensioning Plan for Ruptured Tendons M1 and M4

Remediation and Repairs

Replace M2 Tendons

- Detensioning of intact M2 tendons
  - Given the condition of the tendon, plan was developed to minimize risk and have no one in the main span unit at the time of detensioning
  - Based on previous ruptures, tendons would slip in the transition diaphragms, reducing the unbalanced tension on the diaphragms as well as the tension in the adjacent spans
  - Tendons were secured along the length of the tension to prevent whiplash
  - Detension sequence A-B-C-D-E

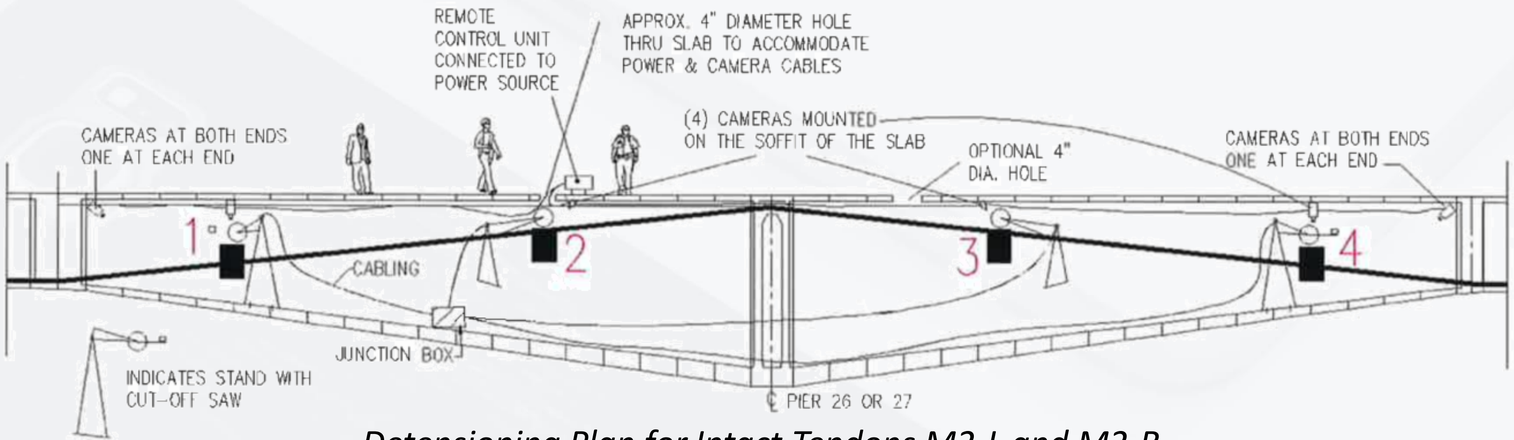


Detensioning Plan for Intact Tendons M2-L and M2-R

Remediation and Repairs

Replace M2 Tendons

- Detensioning of intact M2 tendons
  - Four remote controlled power saws were used with a control unit on the deck
  - Cameras were installed with each saw and in each span
  - Personnel were cleared from the inside the unit and not permitted to reenter until the condition was confirmed through the cameras
  - Short term traffic closure during cutting until cleared by SCDOT



Detensioning Plan for Intact Tendons M2-L and M2-R

Remediation and Repairs

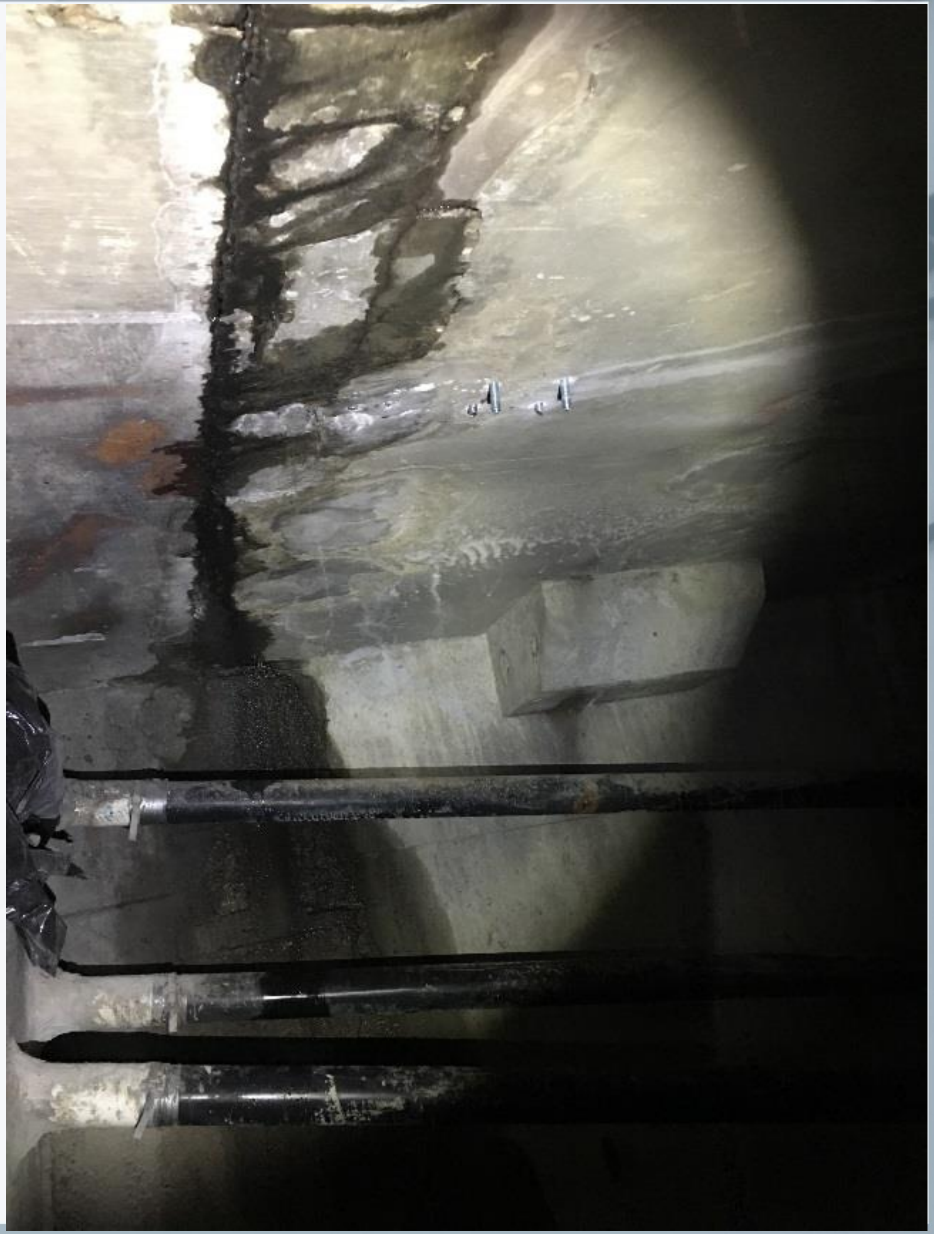
Replace M2 Tendons

- M2-L and M2-R tendons were replaced one at a time
- Inspection of the tendons revealed corrosion, but was not as extensive as anticipated

Remediation and Repairs

P24 Segment Joint Repair

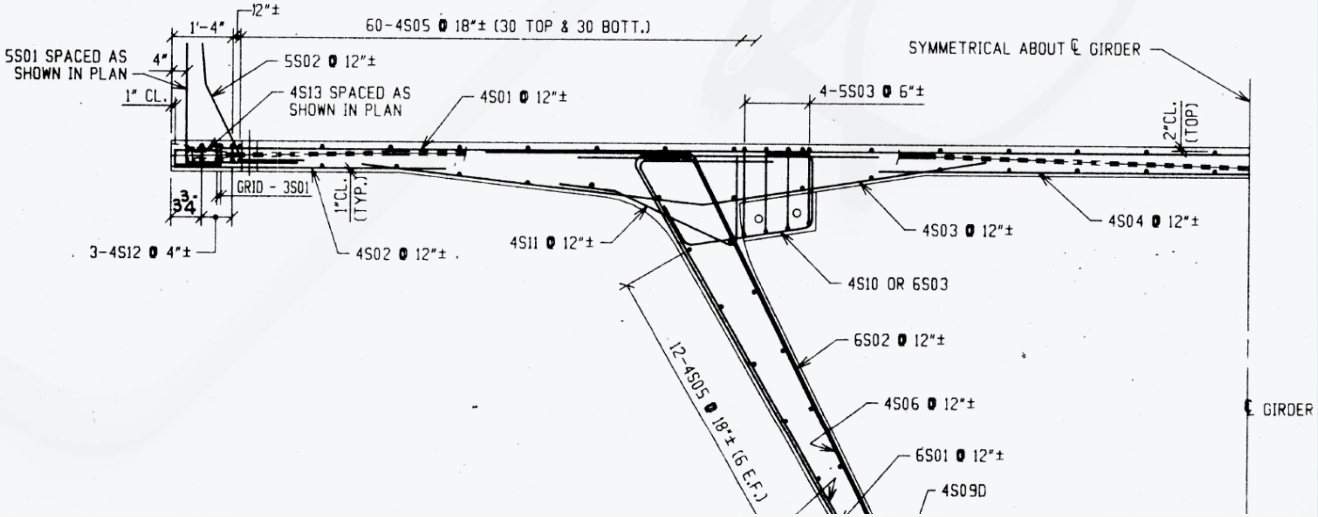
- Leaking and damaged joint at P24 diaphragm, both structures
- Joint further damaged in prior efforts to seal it
- Visible differential displacement under truck loads



Remediation and Repairs

P24 Segment Joint Repair

- Joint is between a pier segment and a typical segment
- Differential deck displacement at joint causing additional spalling and deterioration
- Needed to control the differential displacements, repair the deck, and seal the joint
- Deck is 8” thick (before milling) and very lightly reinforced, so limited shear capacity if a frame was added



Remediation and Repairs

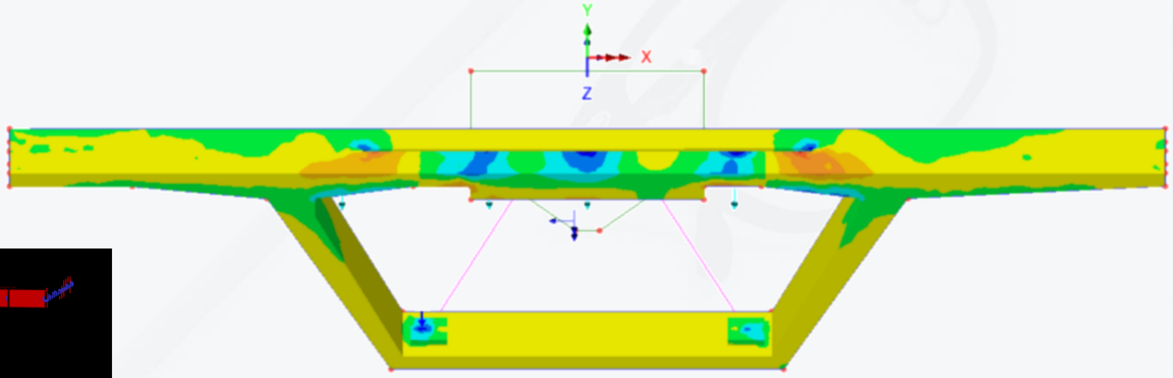
P24 Segment Joint Repair

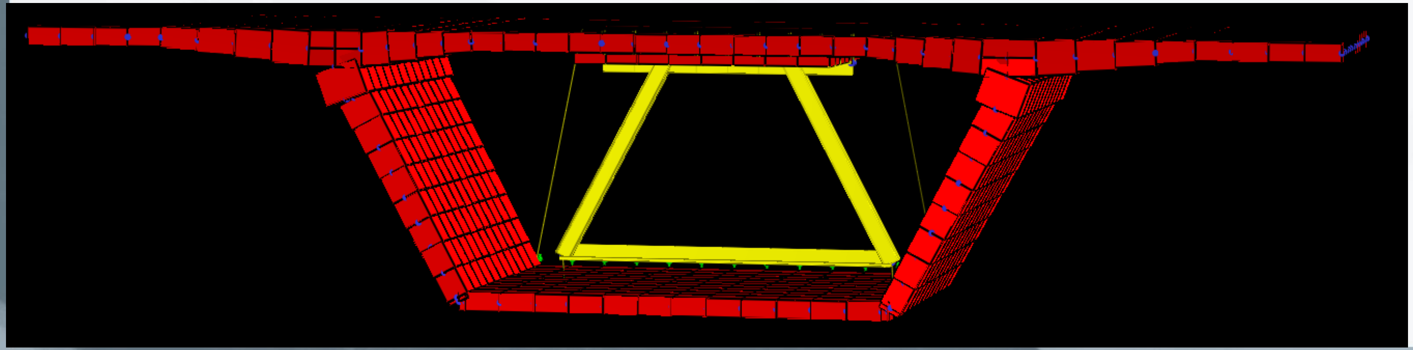
- Two-part solution:
    - Steel frame to limit the displacement of the deck
    - Precast drop slab to additional shear capacity to the deck
- Steel frame designed to be removeable to provide anchor access
- Drop slab is connected to the top slab with epoxy and a grid of post-tensioned rods for composite action

Remediation and Repairs

P24 Segment Joint Repair

- Finite element models (LUSAS and LARSA 4D) were used to determine:
  - Distribution of live loads into the steel frame
  - Permanent contact compression stress required to ensure composite behavior
  - Loadings imparted on the lightly reinforced bottom slab under the frame
  - Length of slab necessary to distribute shear stress
  - Final differential displacements

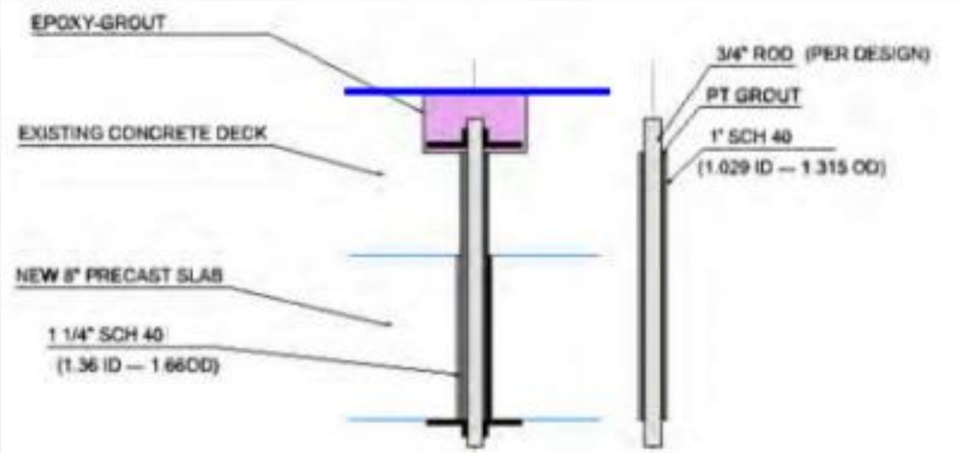




Remediation and Repairs

P24 Segment Joint Repair

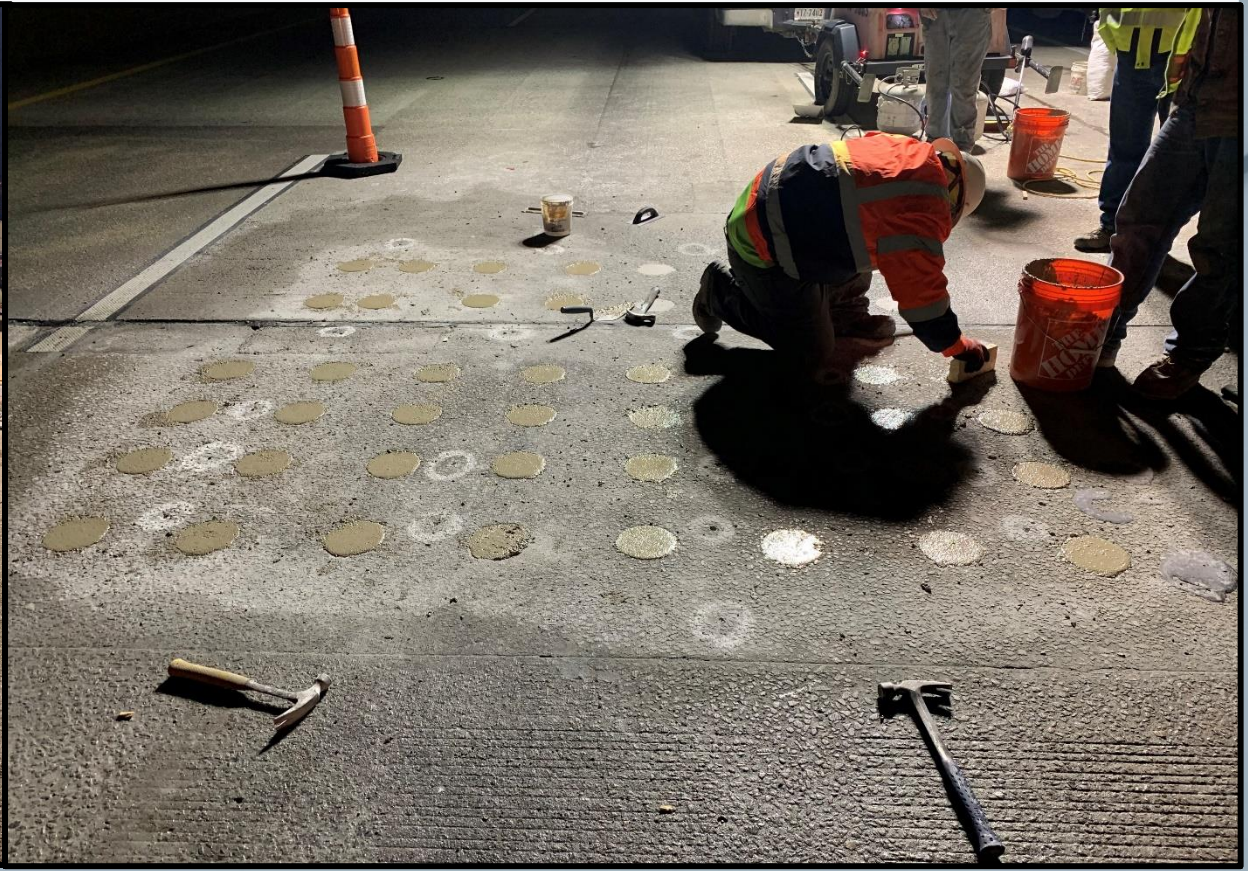
- Drop slabs were precast inside the bridge
- Prefabricated Double-Corrosion Protection (DCP) Rods used to join slab and deck



Remediation and Repairs

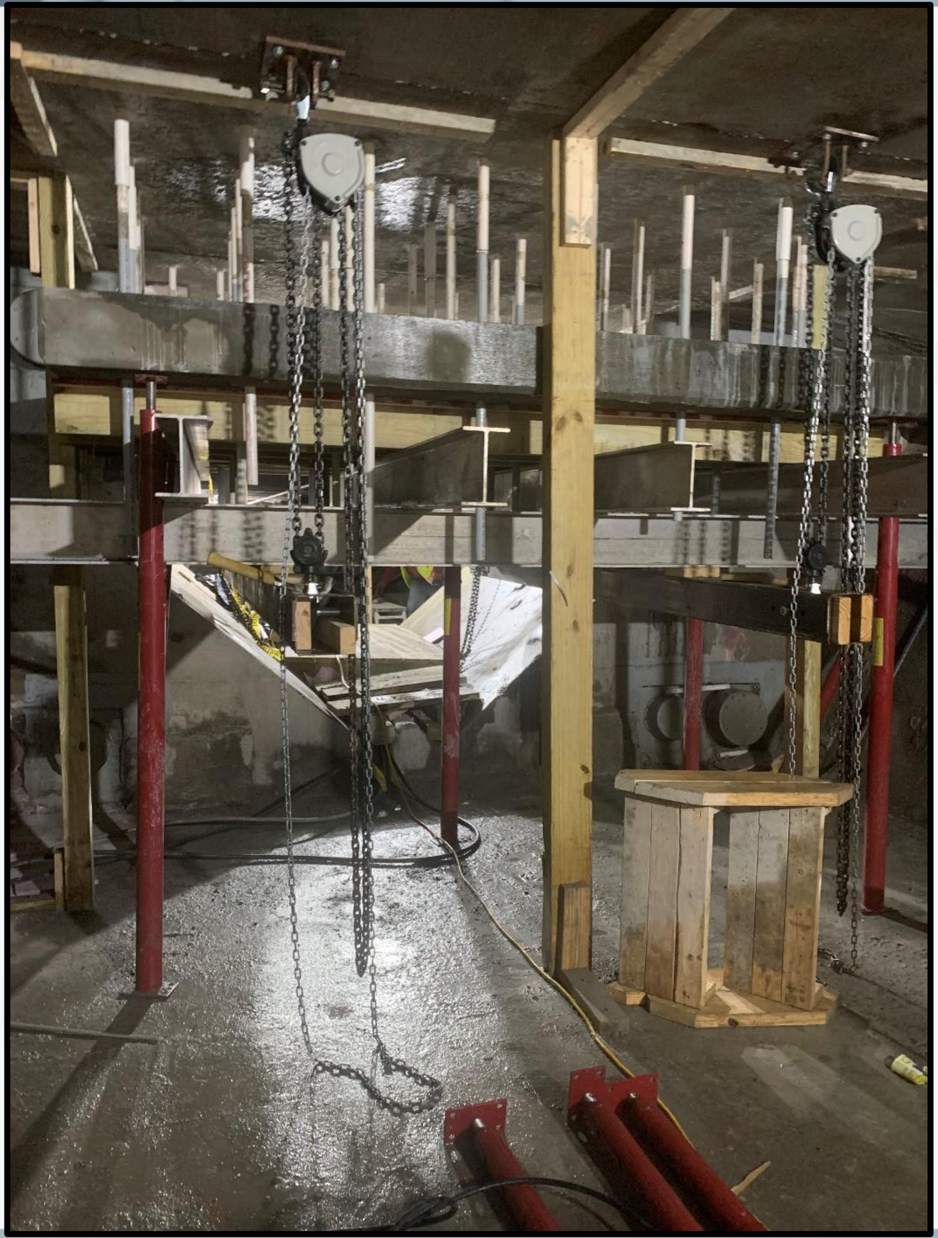
P24 Segment Joint Repair

- DCP rods installed through core holes in top slab



Remediation and Repairs

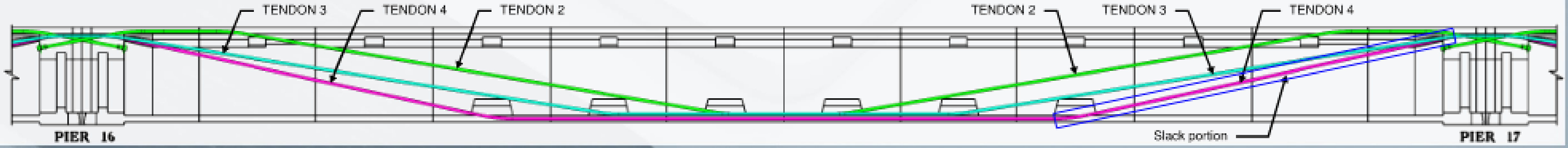
P24 Segment Joint Repair



Remediation and Repairs

WB Span 16 Supplemental Tendons

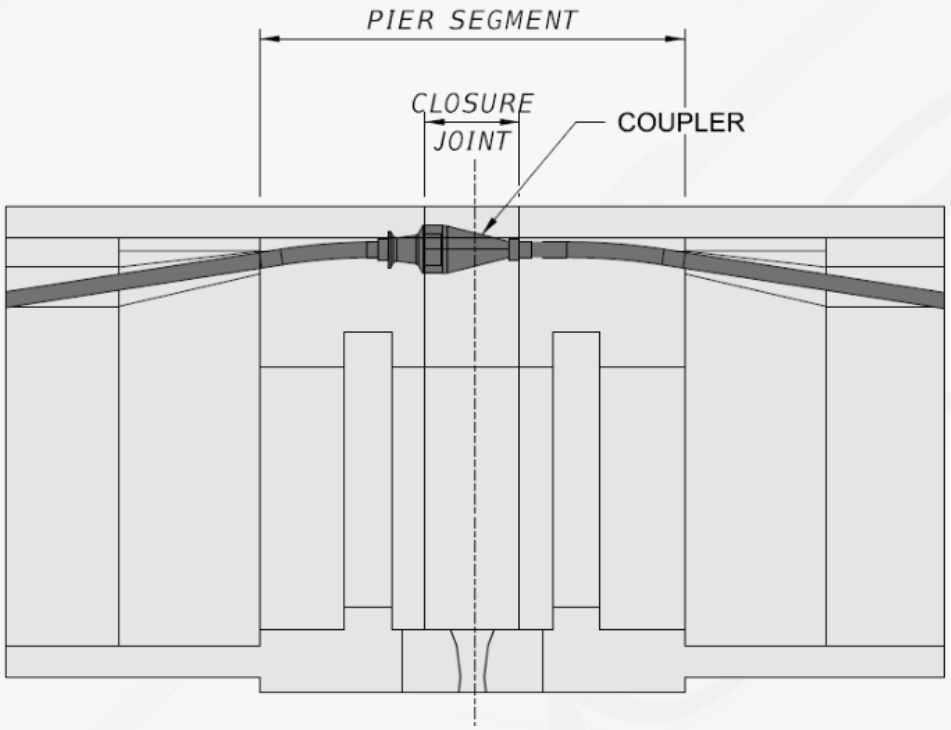
- Draped portion of Tendon 4S found to be during assessment phase
- Several bulges in the HDPE duct
- Opened in two locations to reveal fractured grout
- Downstation end of tendon still had tension
- No evidence of corrosion or water infiltration of the tendon or at the diaphragm

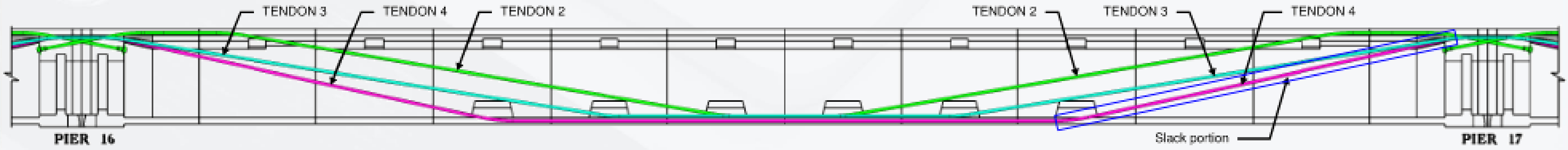


Remediation and Repairs

WB Span 16 Supplemental Tendons

- Replacement challenges
  - Tendon is coupled to a tendon in the adjacent span
  - Tendon profile becomes internal to the bottom slab





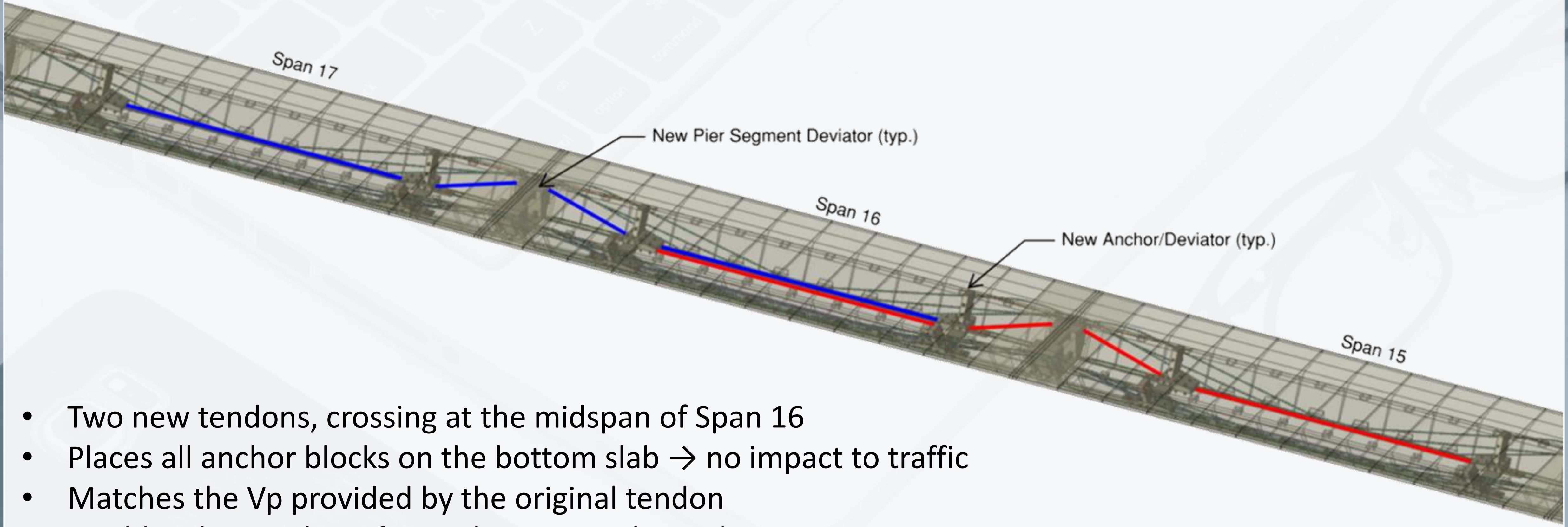
Remediation and Repairs

WB Span 16 Supplemental Tendons

- Supplemental design requirements
  - Replace both shear and moment capacity
  - Must not prevent remediation for other tendons
- Supplemental design challenges
  - Diaphragms are small and congested with reinforcing and transverse PT
  - Top slab and interior haunches are relatively thin

Remediation and Repairs

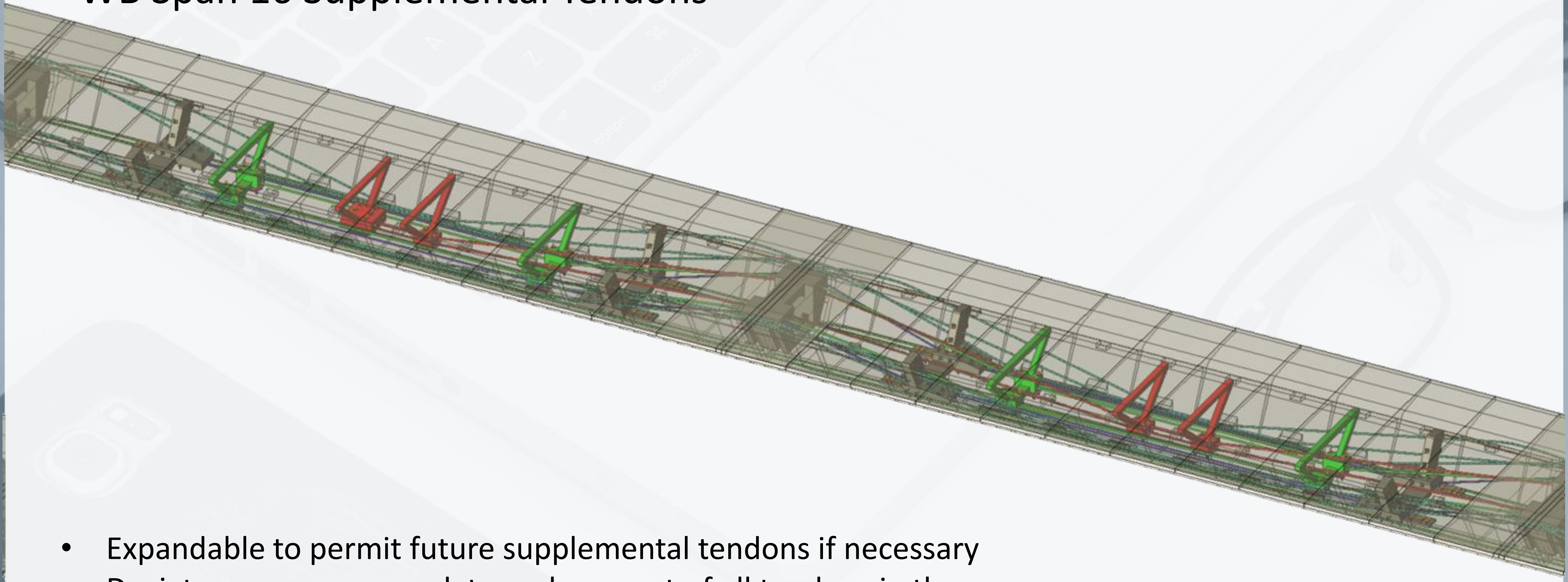
WB Span 16 Supplemental Tendons



- Two new tendons, crossing at the midspan of Span 16
- Places all anchor blocks on the bottom slab → no impact to traffic
- Matches the Vp provided by the original tendon
- Doubles the number of strands crossing the midspan
- Provides redundancy for existing coupled tendon in adjacent span

Remediation and Repairs

WB Span 16 Supplemental Tendons

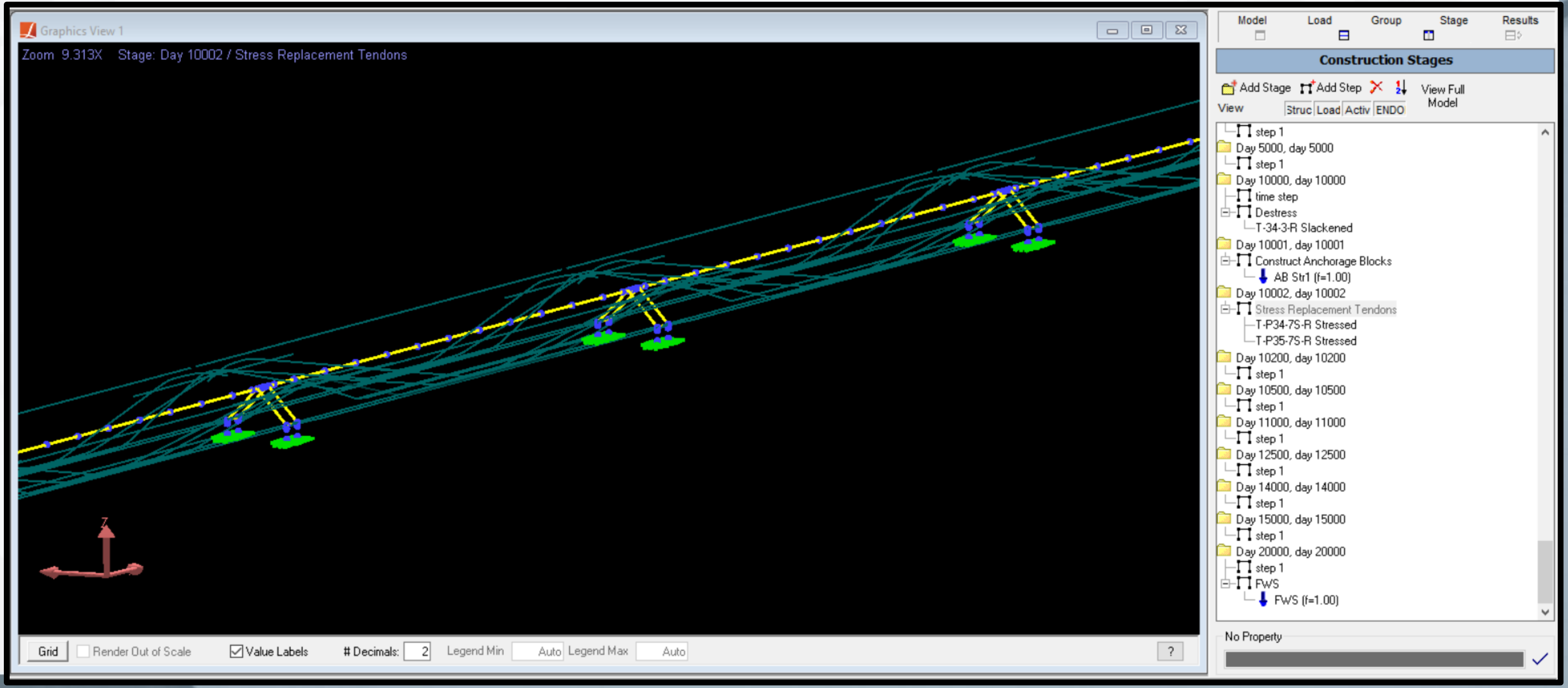


- Expandable to permit future supplemental tendons if necessary
- Deviators can accommodate replacement of all tendons in the span

Remediation and Repairs

WB Span 16 Supplemental Tendons

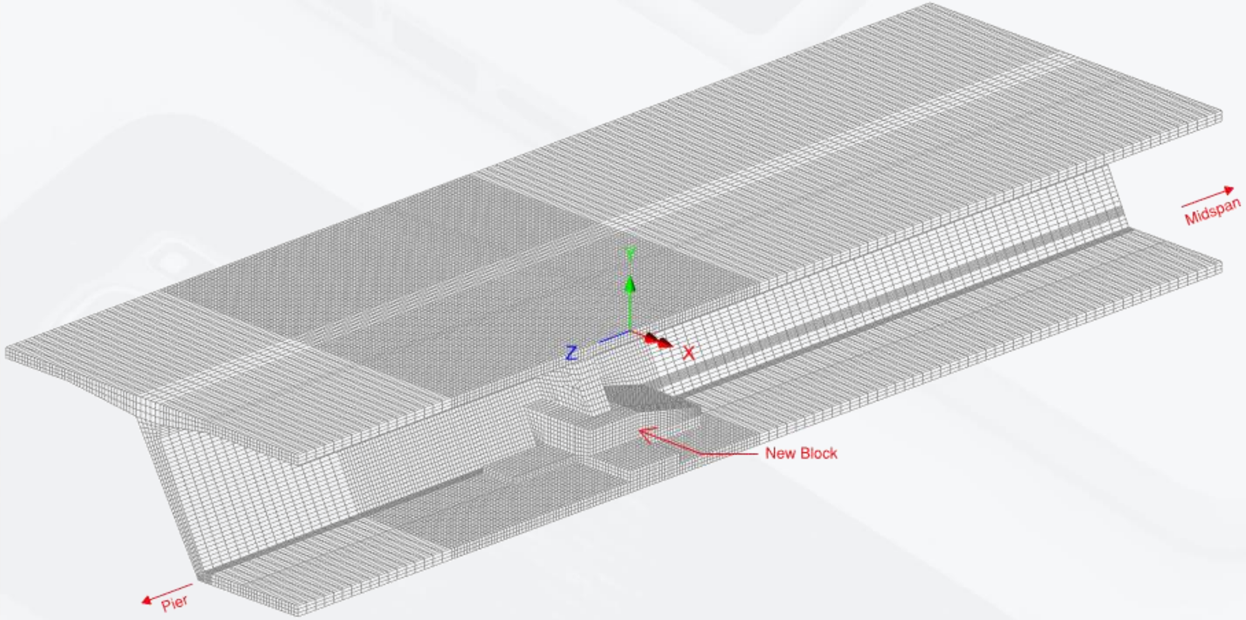
- Longitudinal and Transverse models developed in LARSA 4D
- Longitudinal design considered the controlling of:
  - Complete loss of existing tendon
  - Partial loss of existing tendon
- AASHTO LRFD

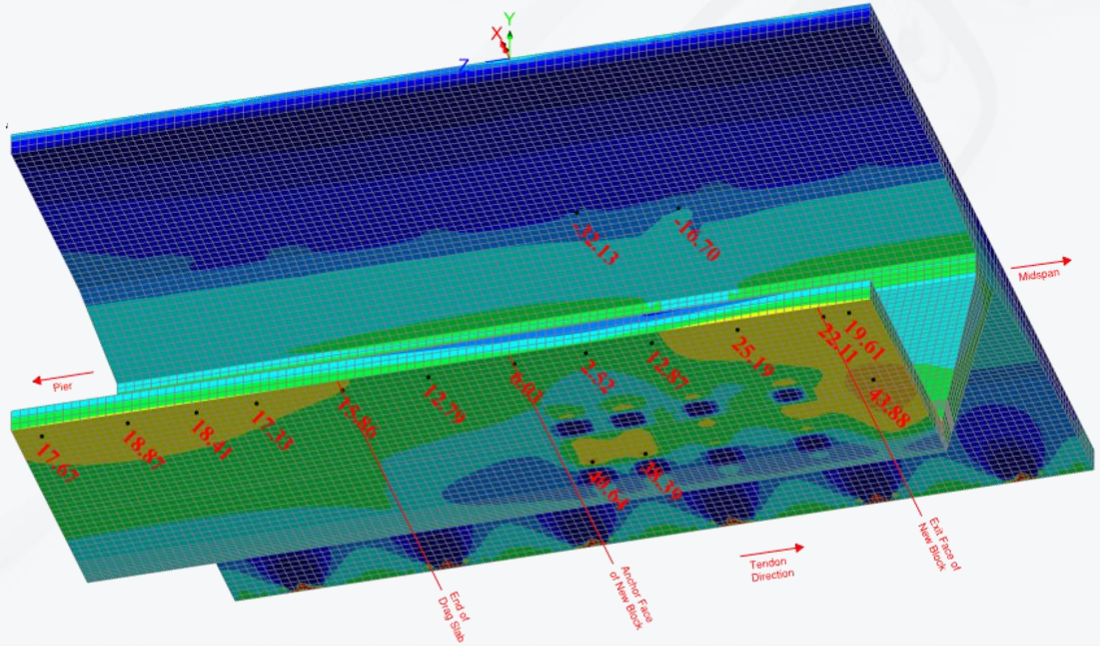


Remediation and Repairs

WB Span 16 Supplemental Tendons

- Local effects on existing structure evaluate with Solid Finite Element Modeling performed in LUSAS
  - Half span model take advantage of symmetry
  - Staged construction
  - Initial stress state loading to match full structure analysis

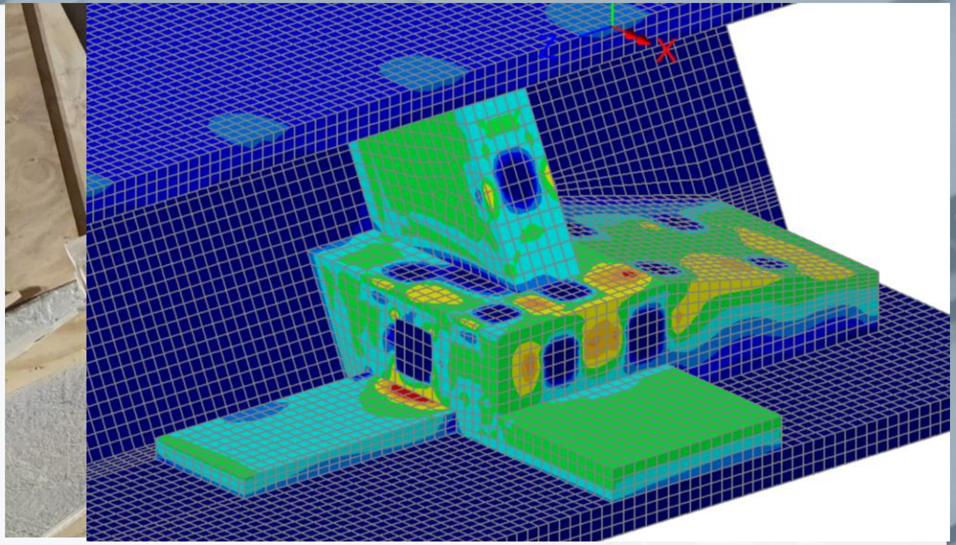


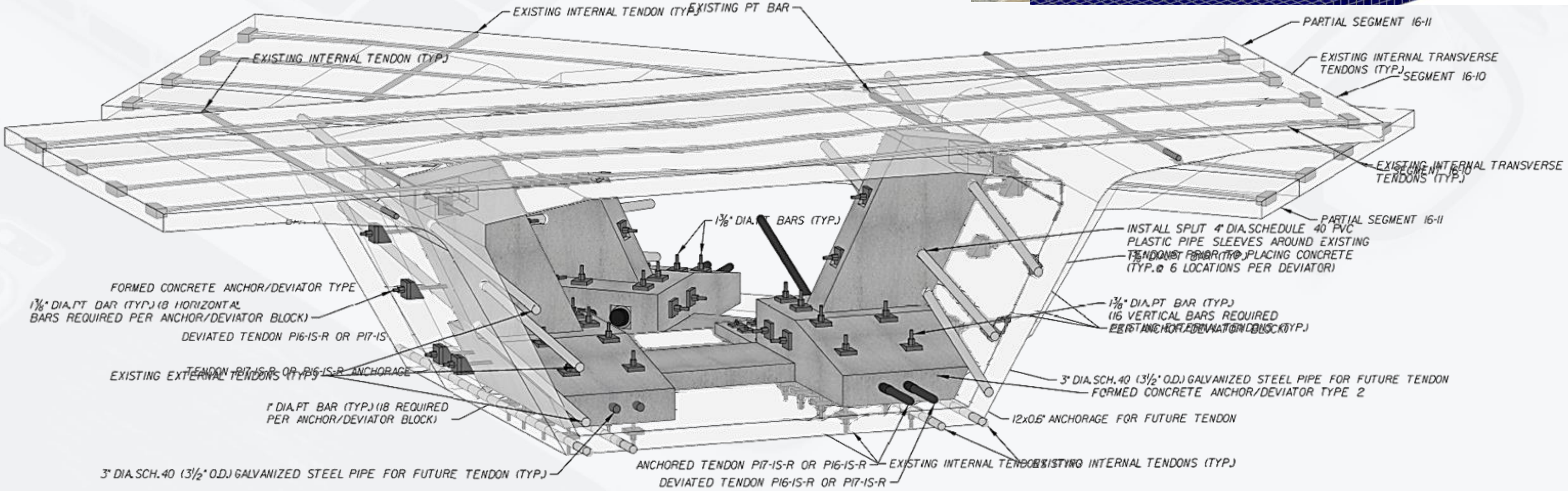


Remediation and Repairs

WB Span 16 Supplemental Tendons

- Anchor/Deviator
  - Anchors two 12-strand tendons
  - Deviates two 12-strand tendons
  - Tension slab distributes local tension behind anchors





Remediation and Repairs

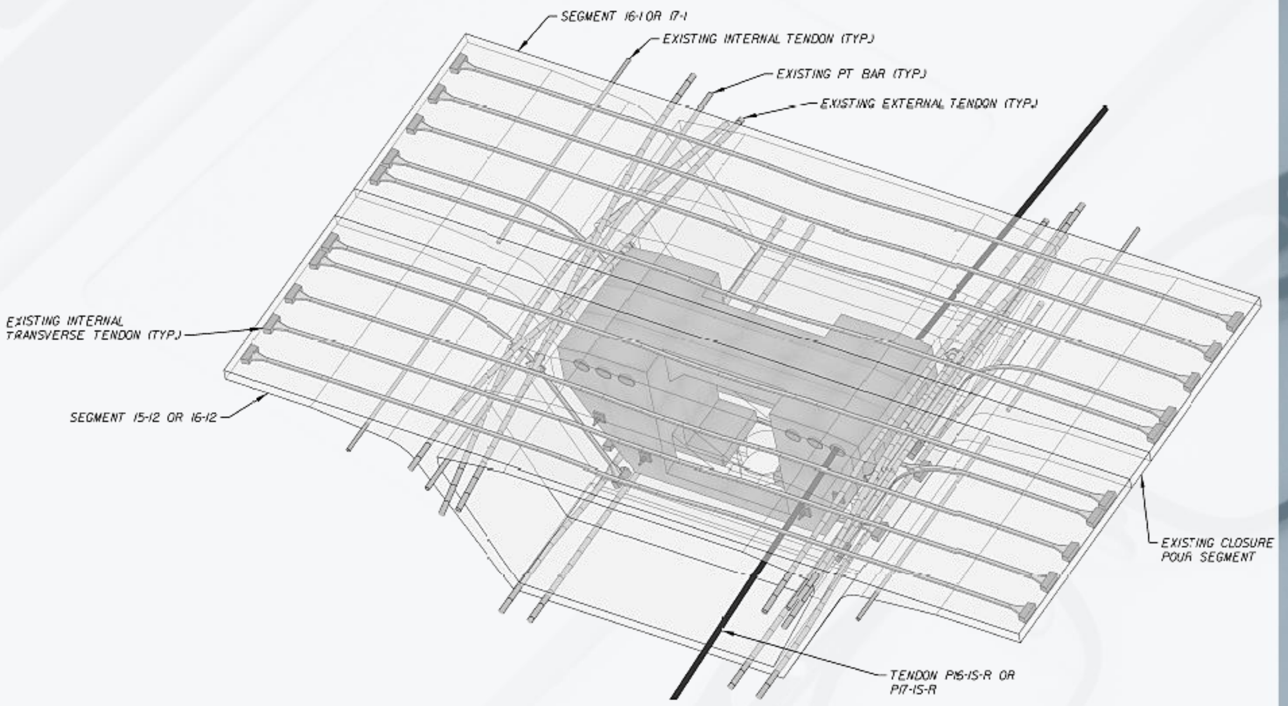
WB Span 16 Supplemental Tendons

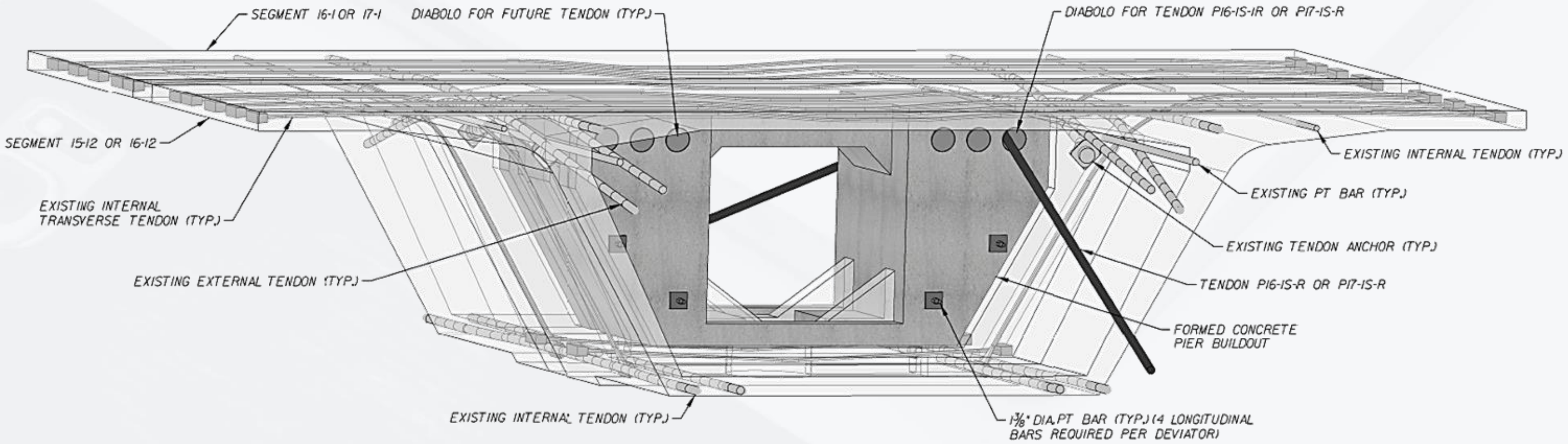
- Anchor/Deviator

Remediation and Repairs

WB Span 16 Supplemental Tendons

- Pier Segment Deviators
  - Designed to accommodate six tendons
  - Utilizes diabolos with preloaded HDPE
  - High point grout vents cast with deviator and accessible on deviator face





Remediation and Repairs

WB Span 16 Supplemental Tendons

- Pier Segment Deviators

Remediation and Repairs

WB Span 16 Supplemental Tendons

- Other Details

CFRP reinforcing at new access opening

PT bar anchors on exterior face of web

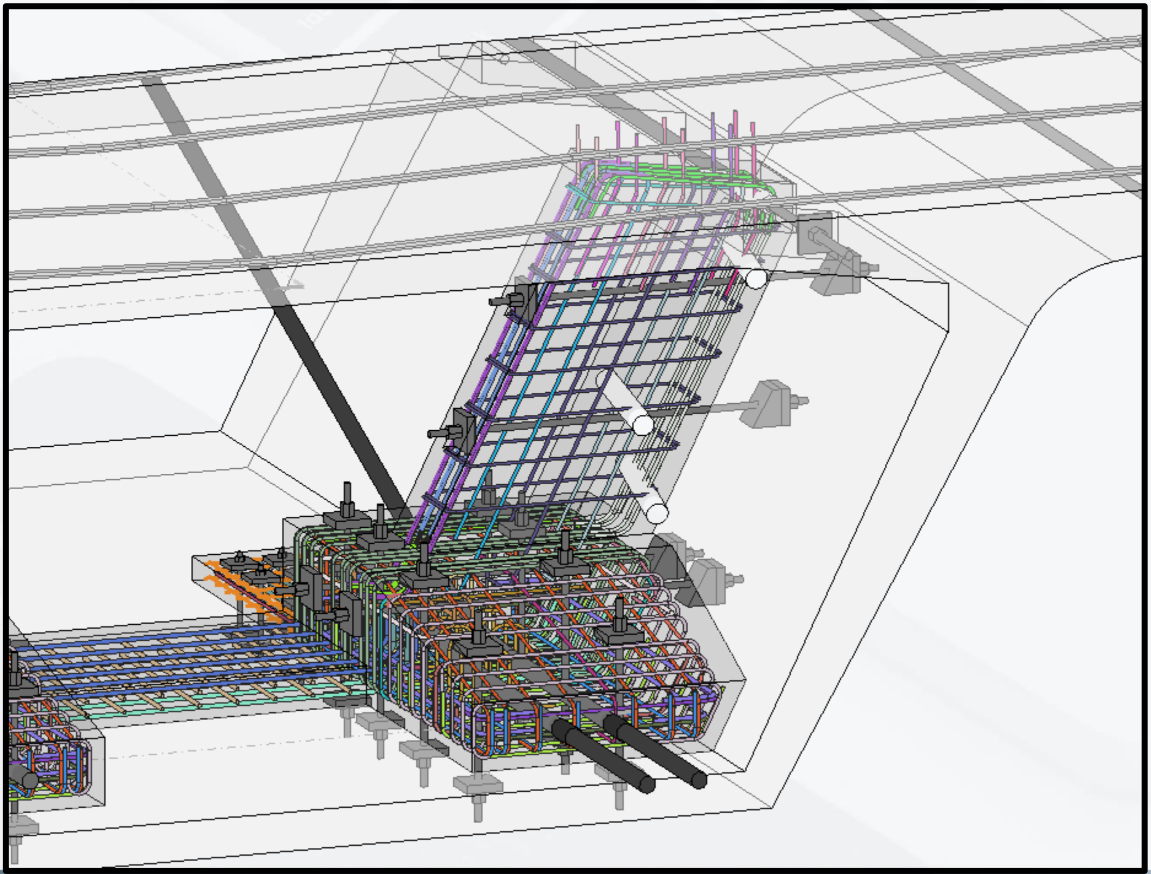
Span 16 Stressing

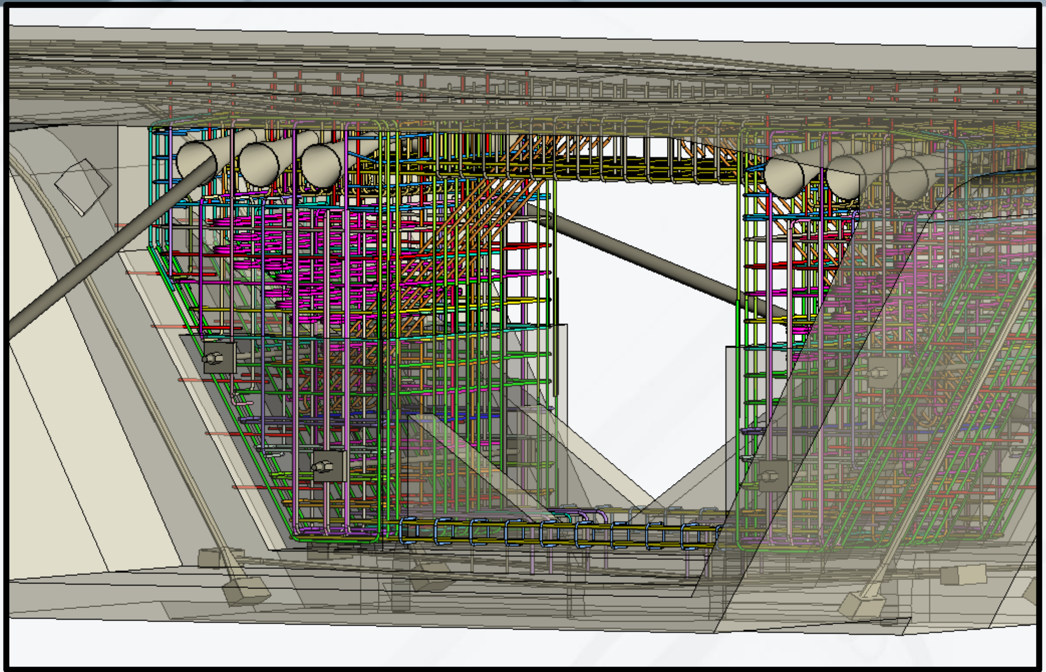
Tendon impregnation

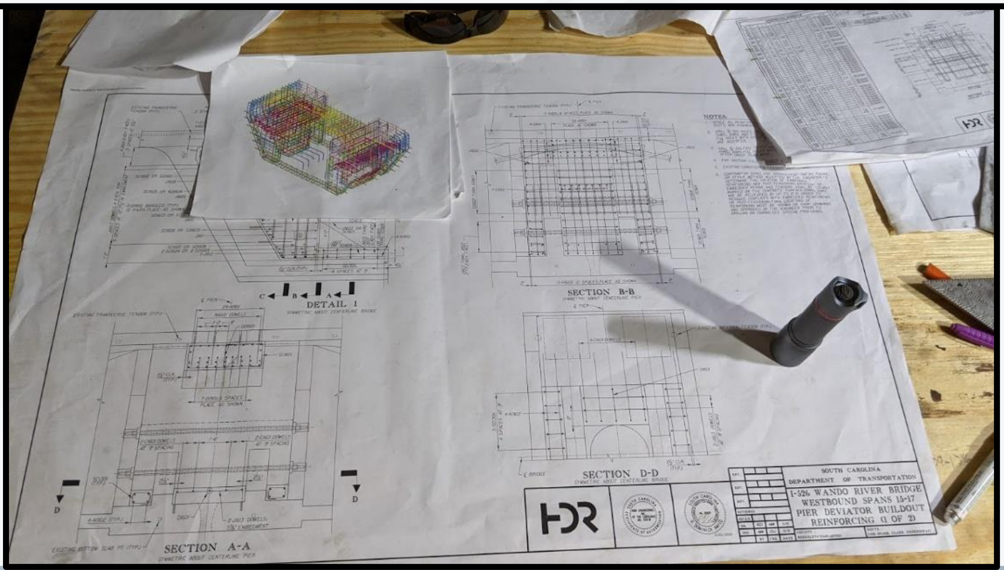
Remediation and Repairs

WB Span 16 Supplemental Tendons

- 3D Drawings

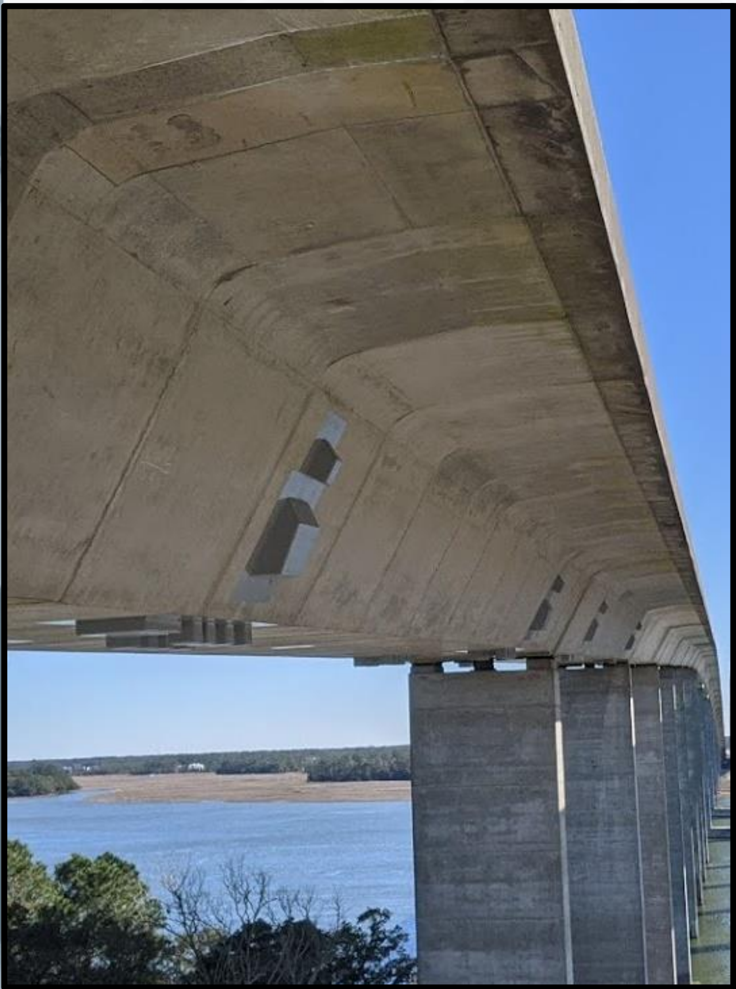






Remediation and Repairs

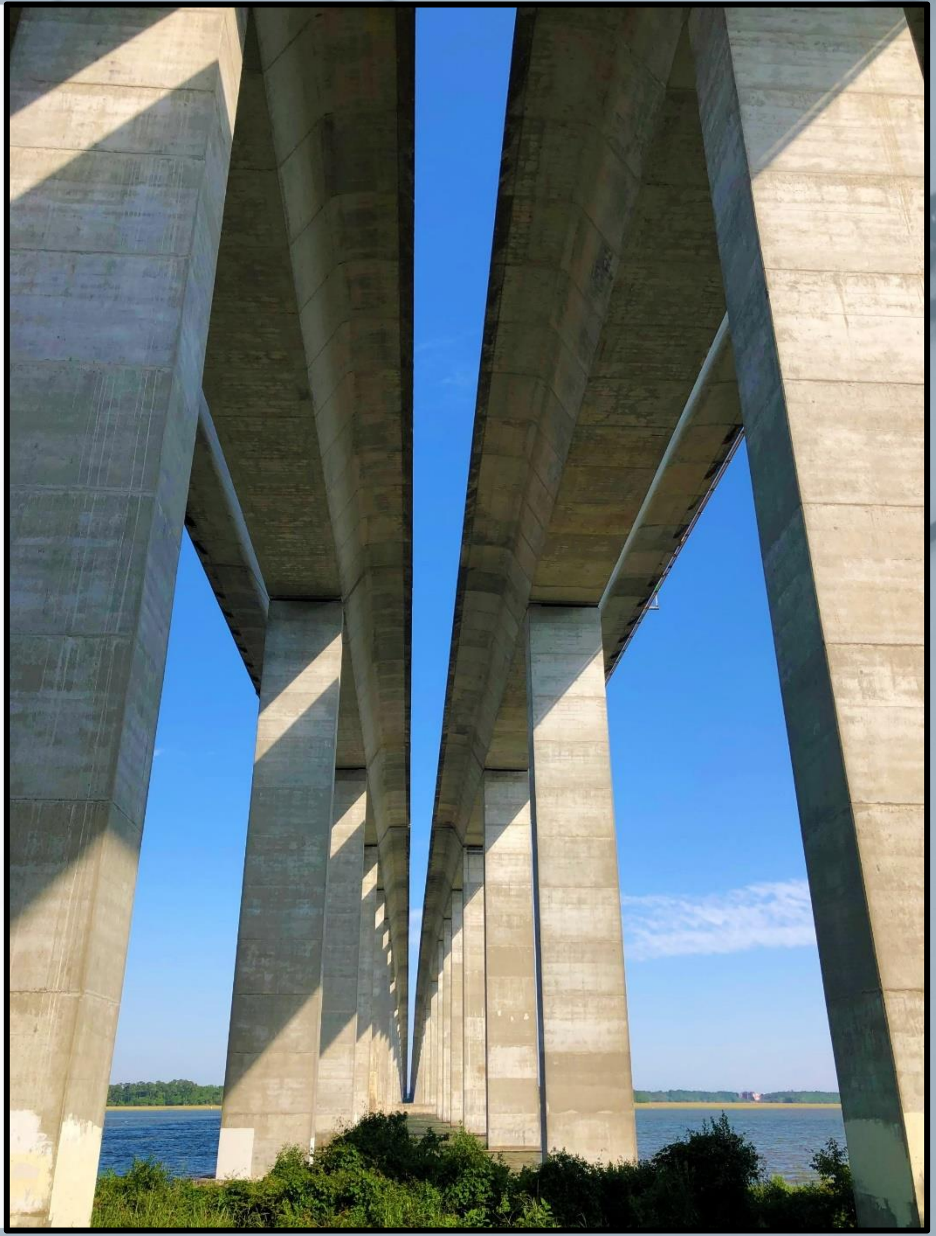
WB Span 16 Supplemental Tendons



Summary

Summary

- Structure Overview
  - Regional importance of the structure
  - Original construction methods
- Assessment Phase
  - Investigation into the cause of the tendon rupture
  - Methods used to evaluate the condition of the PT system
- Remediation and Repairs
  - Tendon replacements
  - Creative applications of post-tensioning in repairing a segment joint
  - Concept for installing draped supplemental post-tensioning



This concludes the Educational Content of this activity

Questions?

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