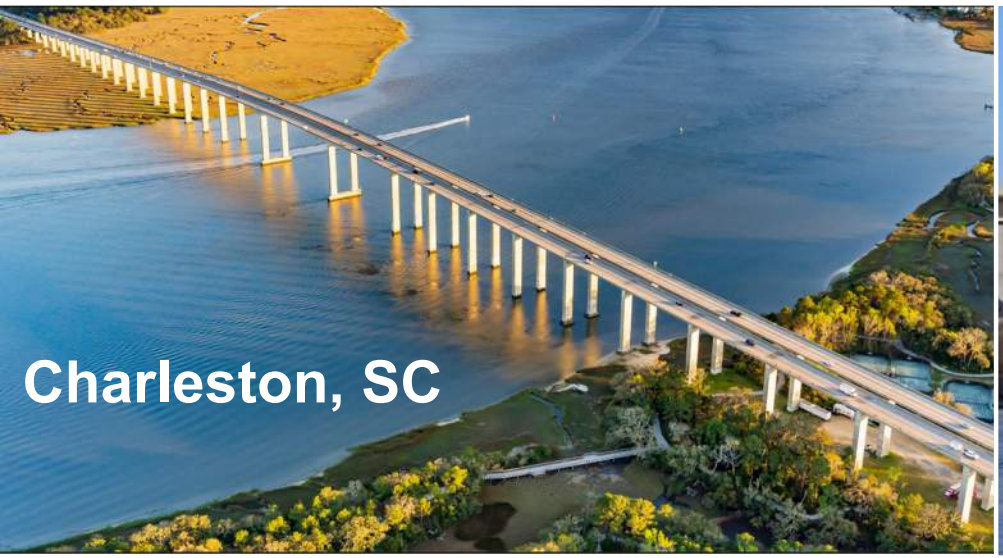
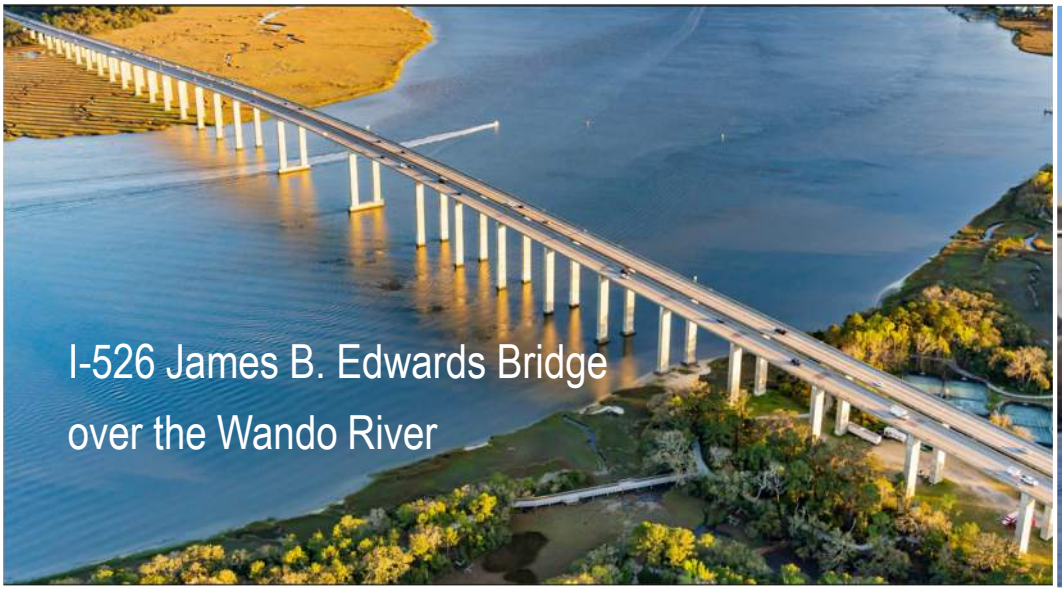


POST-TENSIONING TENDON REPAIRS OF TWO SEGMENTAL CONCRETE BRIDGES

Ying Tan, PhD, PE

HDR



I-526 James B. Edwards Bridge
over the Wando River

N-2 Missouri River Bridge

EOR: Nick Amico (Complex Structures Lead)

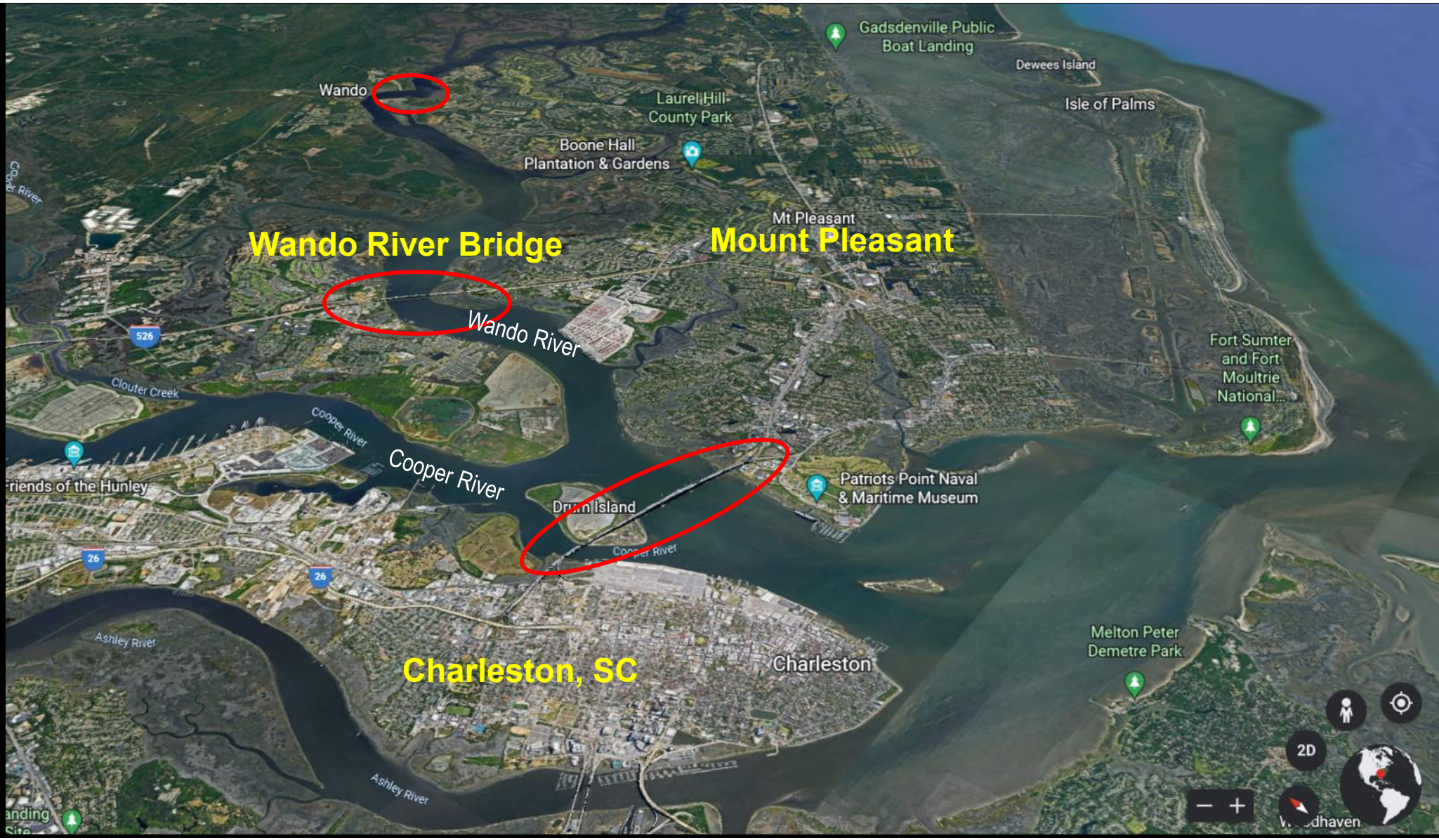
Design Team: HDR South Atlantic Area Complex Bridge Group

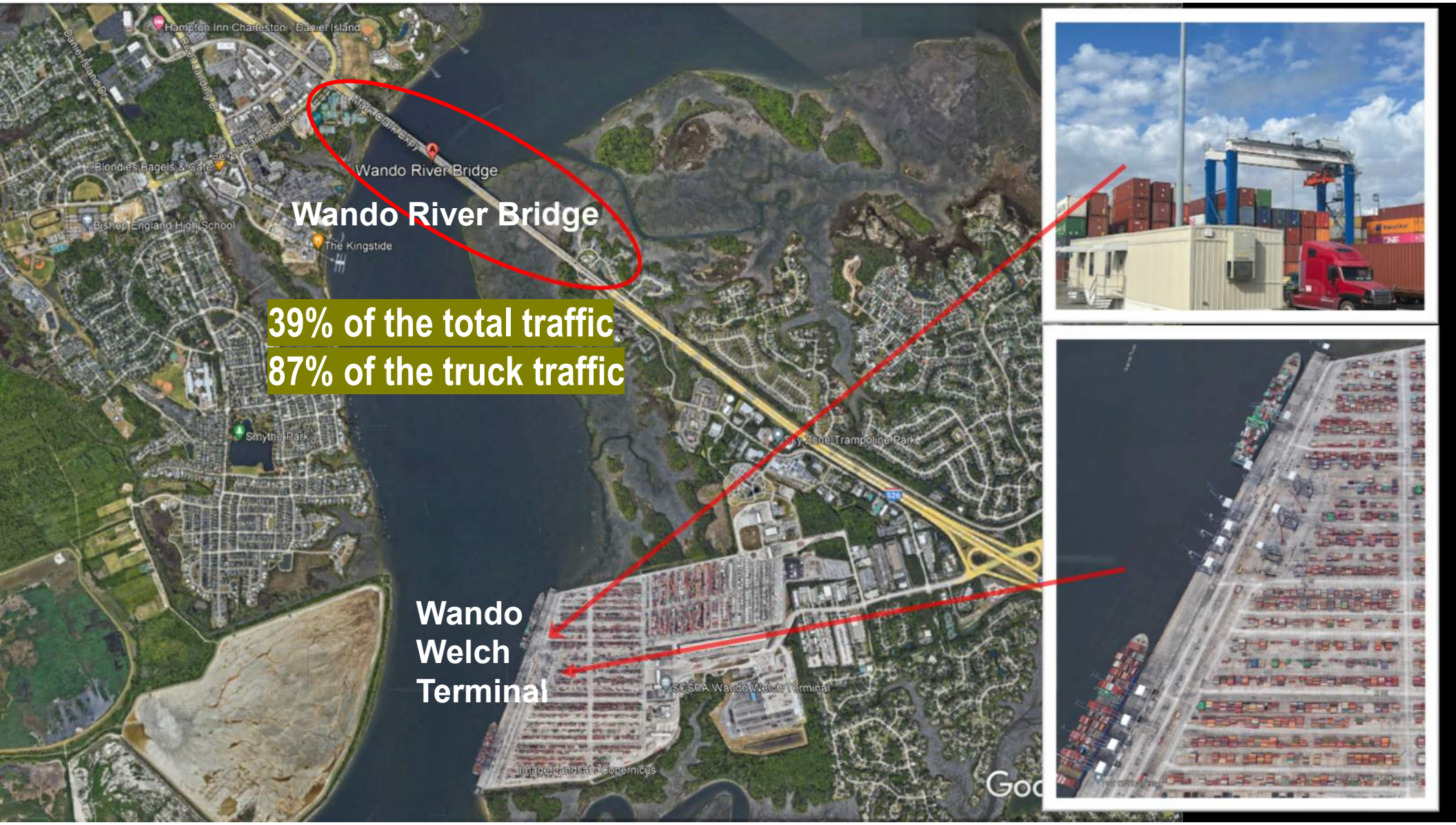
I-526 James B. Edwards Bridge over the Wando River

Charleston, SC

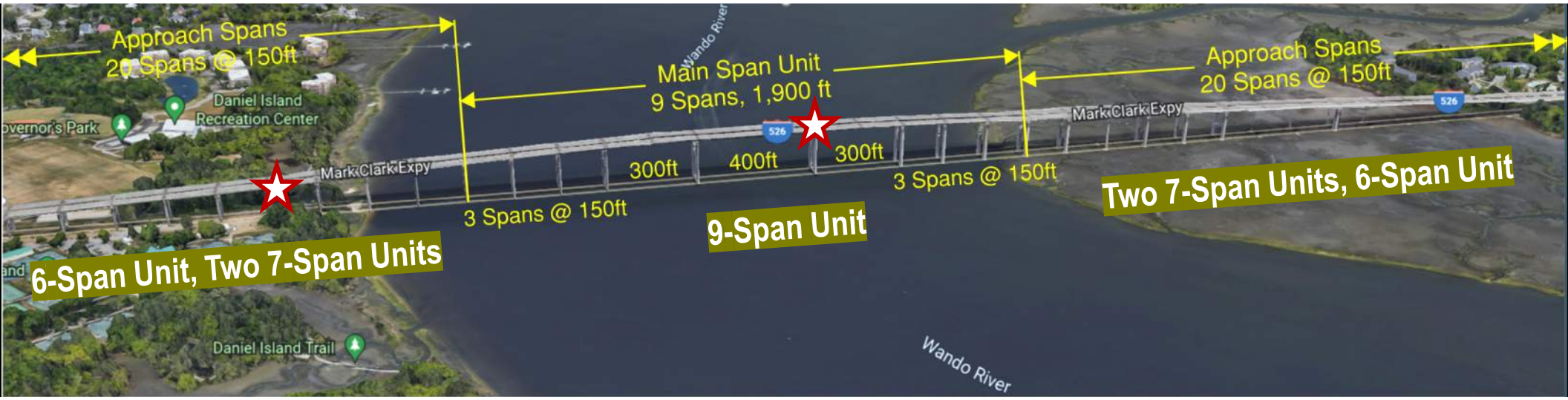
Post-Tensioning Tendon Inspection and Repairs


Structure
Overview


Wando
Gadsdenville Public Boat Landing
Dewees Island
Isle of Palms
Laurel Hill County Park
Boone Hall Plantation & Gardens
Mt Pleasant
Wando River Bridge
Mount Pleasant
Wando River
526
Clouter Creek
Cooper River
Cooper River
Fort Sumter and Fort Moultrie National...
Patriots Point Naval & Maritime Museum
Drum Island
26
26
Ashley River
Charleston, SC
Charleston
Melton Peter Demetre Park
Ashley River
2D


Wando River Bridge
Wando River Bridge
39% of the total traffic
87% of the truck traffic
Wando
Welch
Terminal

Wando Overview



Erected: 1989
Opened: 1991

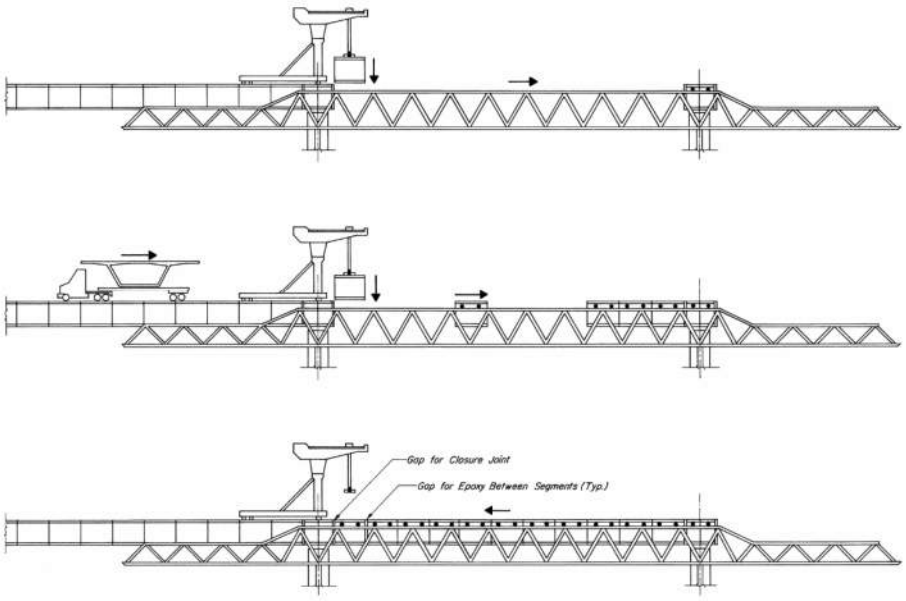
Symmetrical Twin Bridges

Each Bridge: 7 units, 49 spans

- Approach Spans at Each End: 3 Units (20 Spans @ 150ft)
- Main Span: 1 Unit (9 Spans)
- Total Length: 7,900ft (1.5miles)

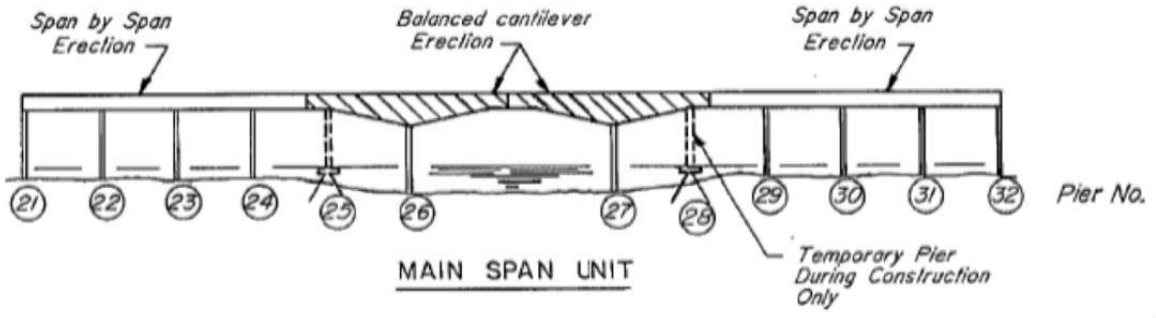
Wando Overview

- Precast, Post-Tensioned Segmental Construction
- **Approach Spans** erected with the Span-by-Span Method



Wando Overview

- **Main Spans** erected with the Balanced Cantilever Method
- Tendons
  - 600 External Draped Longitudinal Tendons
  - 792 Internal Longitudinal Tendons

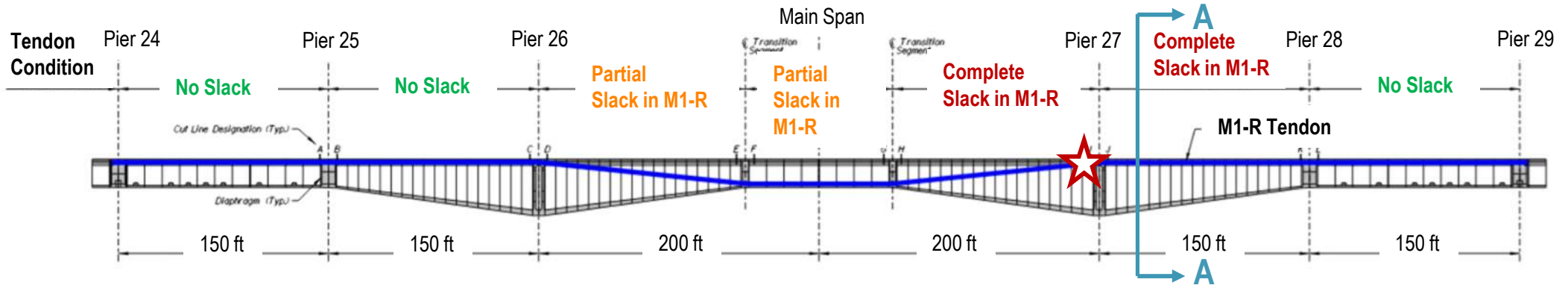


Sept. 2016

Main Span Unit

M1-R Tendon Ruptured

- 19 Strand External Tendon
- 1,010 ft long
- No other distress evident



SCDOT Responded rapidly…

- Near daily inspection
- Installed crack monitors at key locations
- Engaged HDR to Model and analyze main span unit
- Closed one traffic lane to reduce load and provide a work zone on the deck
- Installed one supplemental tendon
- Detensioned and replaced the ruptured 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

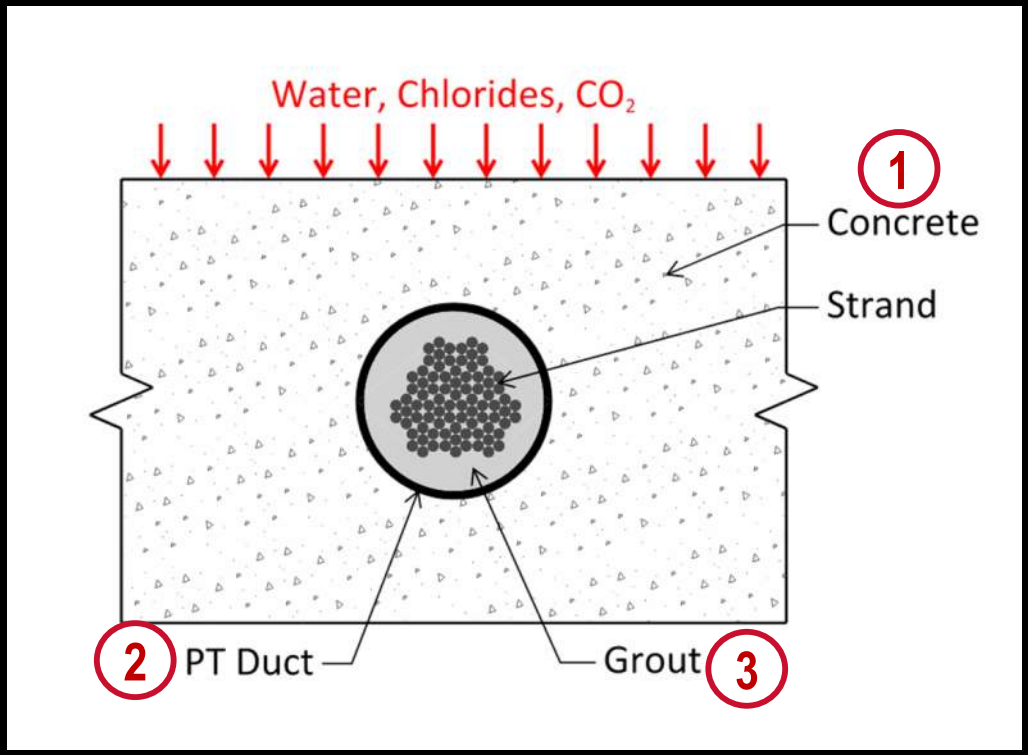
Identify sources and extent of corrosion in the external tendons

Propose courses of remedial action

Tendon Protection

Physical barrier to water and oxygen: 3 layers of protection

Chemical Barrier: High pH grout forms a protective oxide film on the strand



Deficiencies to look for…

Structure deficiencies

- Cracks, spalls, voids
- Segmented, unsealed ducts
- Cracked or punctured ducts
- Unprotected grout ports

Grout deficiencies

- Soft grout
- Segregated grout
- Voids and poor grout cover
- Microcracking

Chemical deficiencies

- Carbonation
- High chloride content
- High sulfate content

Assessment Phase

M1-R Tendon Investigation

Grout material issue?

Steel material issue?

Construction method issue?

External Tendon Assessment

Walkthrough and Visual Inspection

- Cracks, spalls, voids
- Open grout ports
- Evidence of water infiltration
- 300 borescope inspections

External Tendon Assessment

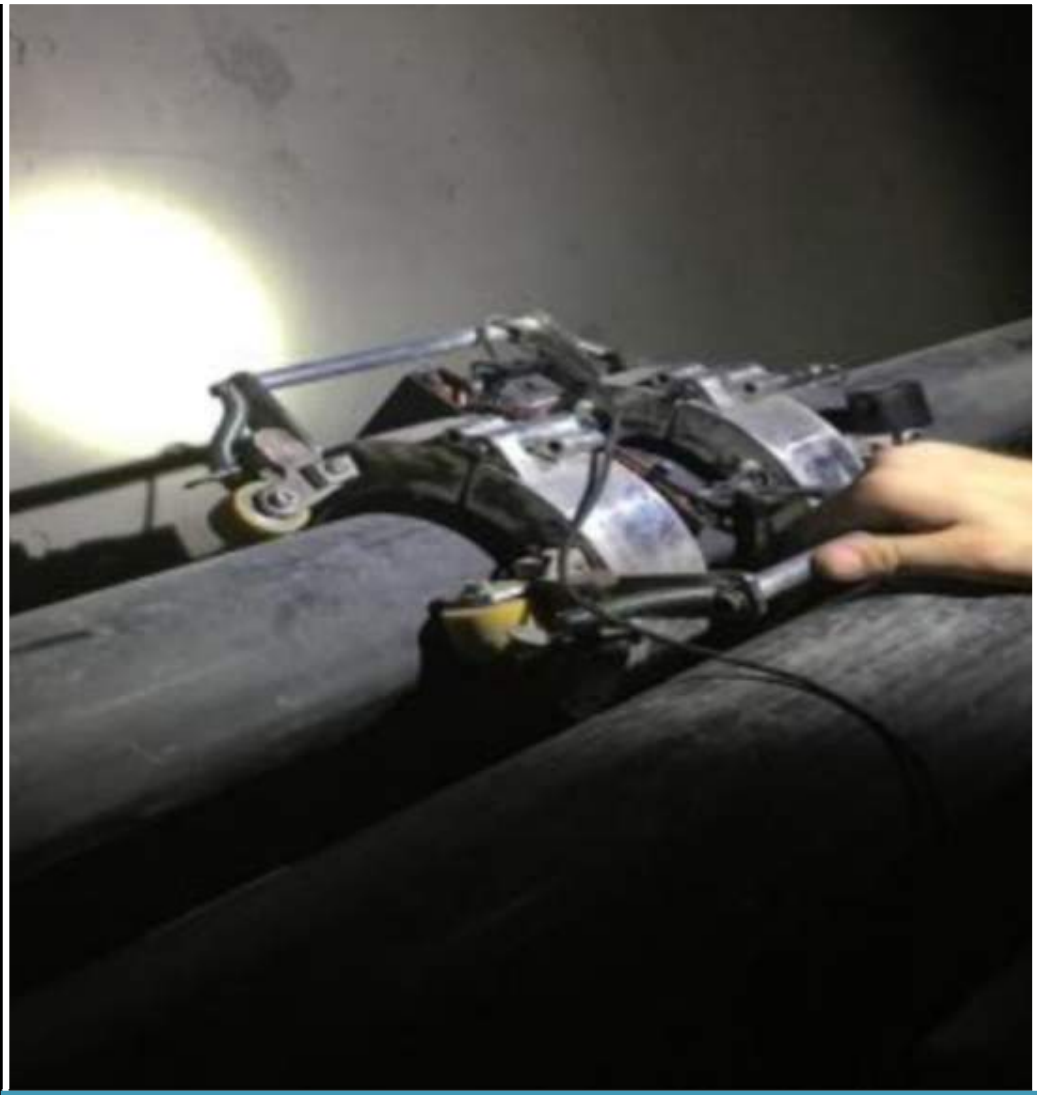
Grout and Material Testing

- Visual grout condition inspection
- Corrosion potential
- Corrosion rate
- Grout tests
- Tensile strength testing
- Duct material tests

External Tendon Assessment

Magnetic Flux Testing

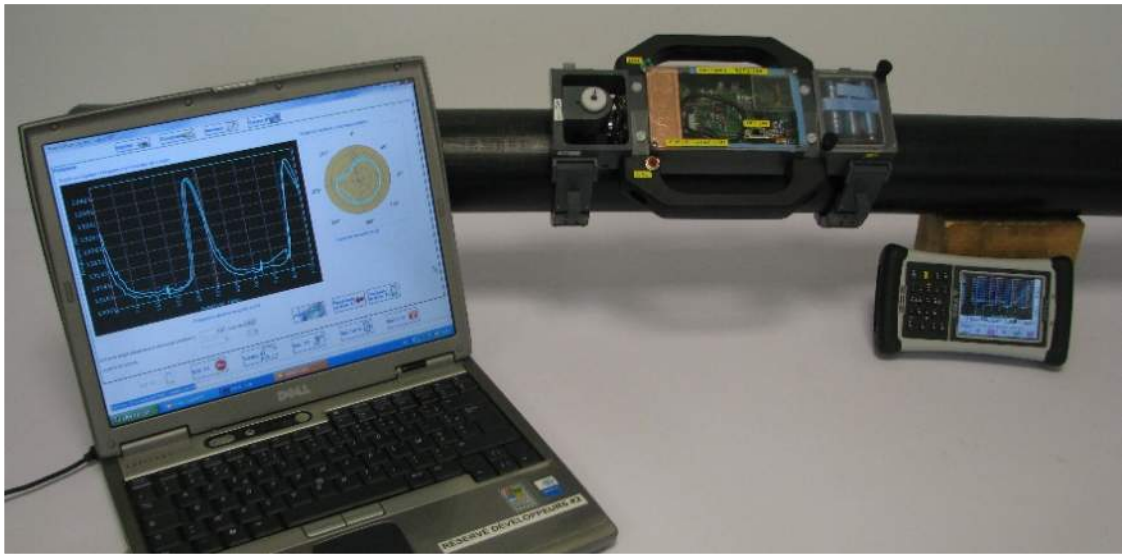
- Locates area of steel section loss
- 24,500 linear feet tested

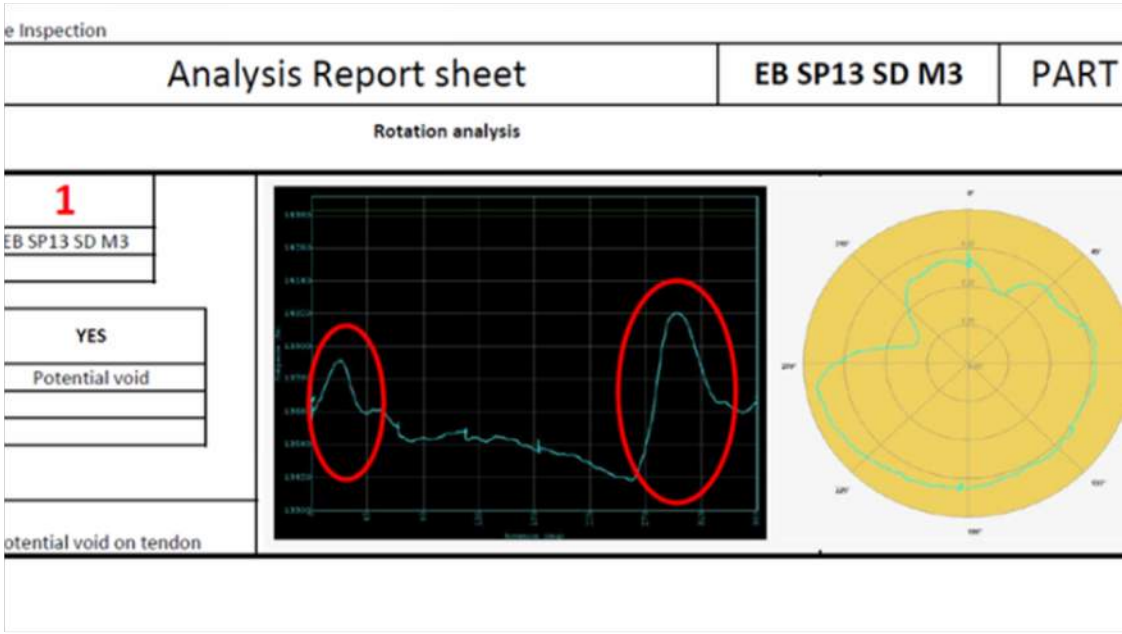


External Tendon Assessment

Capacitive Probe Inspection

- Locates voids, water, white paste, soft grout
- 44,445 linear feet tested





External Tendon Assessment

Findings

At the rupture location

- Severe corrosion of the strand
- Duct was approximately 80% empty
- Very low pH (around 5)
- Water infiltration


Leaking Segment Joint


Severe corrosion of the strand

External Tendon Assessment

Findings - Away from the rupture

Good News

- Tendons – majority in good condition with little corrosion
- Grout - overall a decent quality

In short: no significant corrosion would be expected if encased in grout

Hmm…

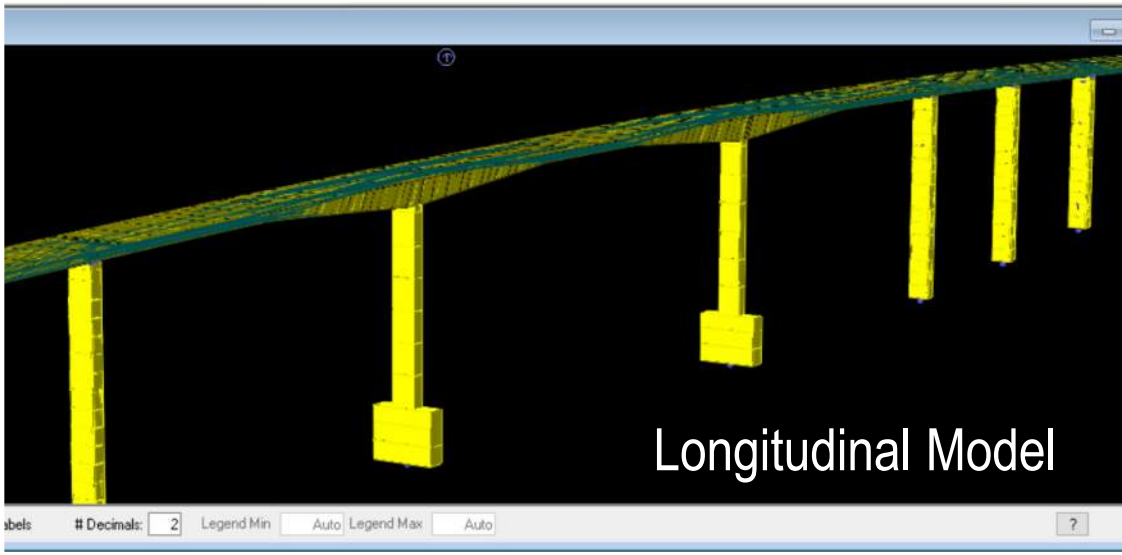
- One detensioned tendon: **M1-R** in WB Main Span Unit
- Two corroded external tendons: **M2-L** & **M2-R** in WB Mian Span Unit
- One detensioned tendon **16-4R** in WB Approach Span Unit

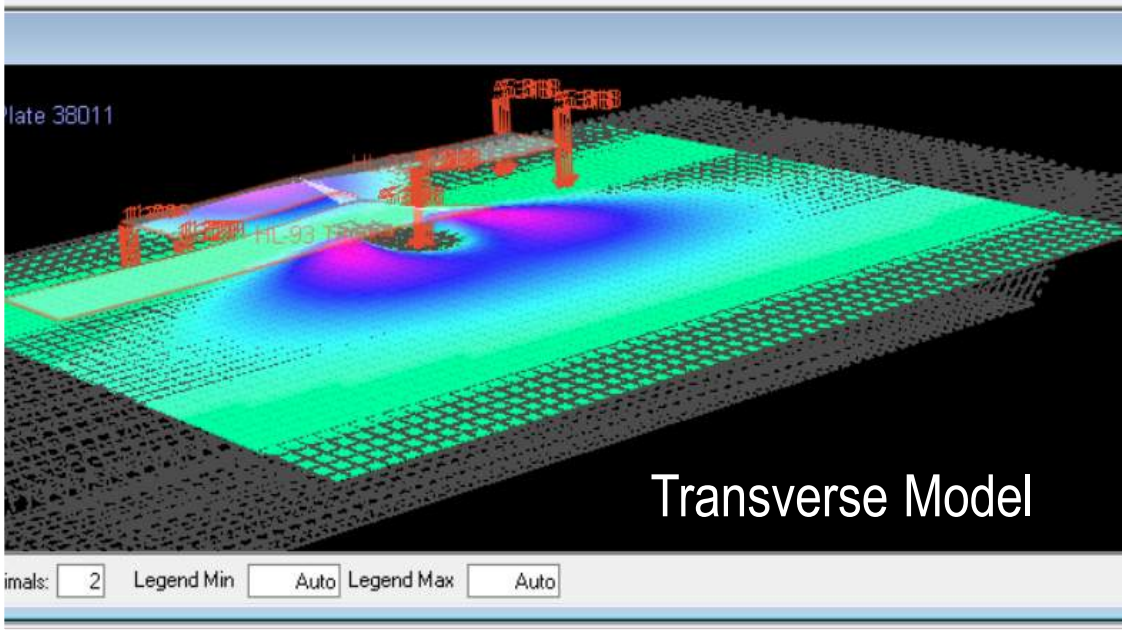
External Tendon Assessment

Modeling and Limited Load Rating

3D Time-Dependent Staged Construction and Live Load Models

- Main Span Unit
- Typical Approach Span Unit
- Transverse Analysis Models



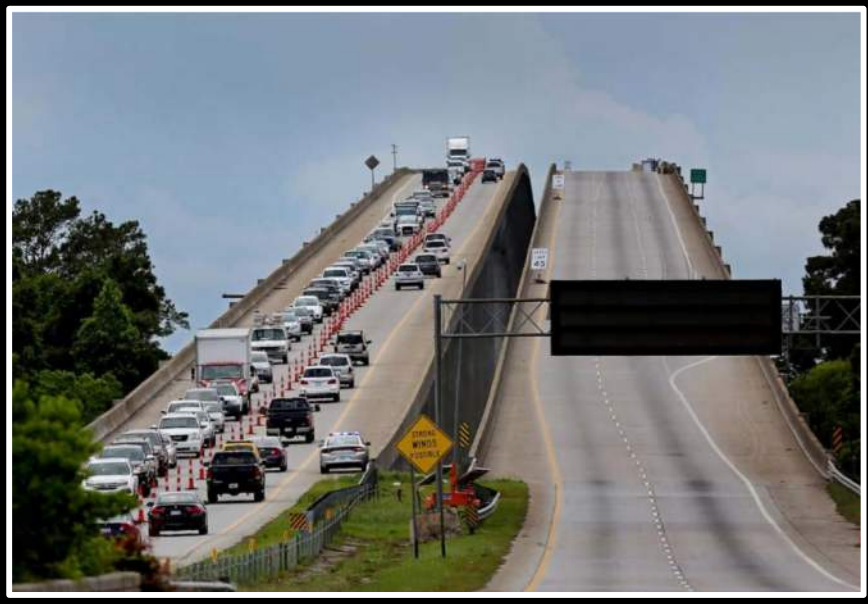


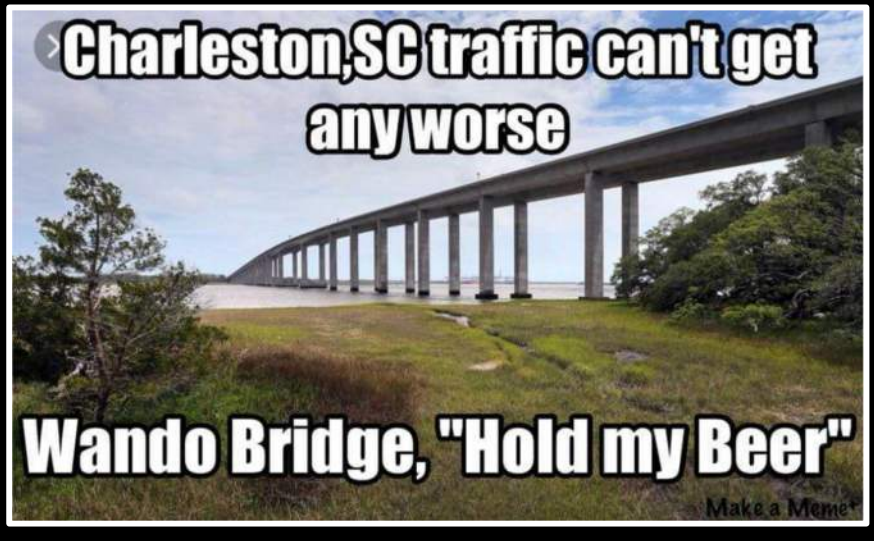
May 2018 …

Again – Main Span Unit

M4-L Tendon ruptured

at same location as M1-R tendon






Repairs
Phase

Main Span Supplemental Tendons

WB structure

- Two supplemental tendons added
- **Reopened after 19 days**

EB structure

- Two supplemental tendons added

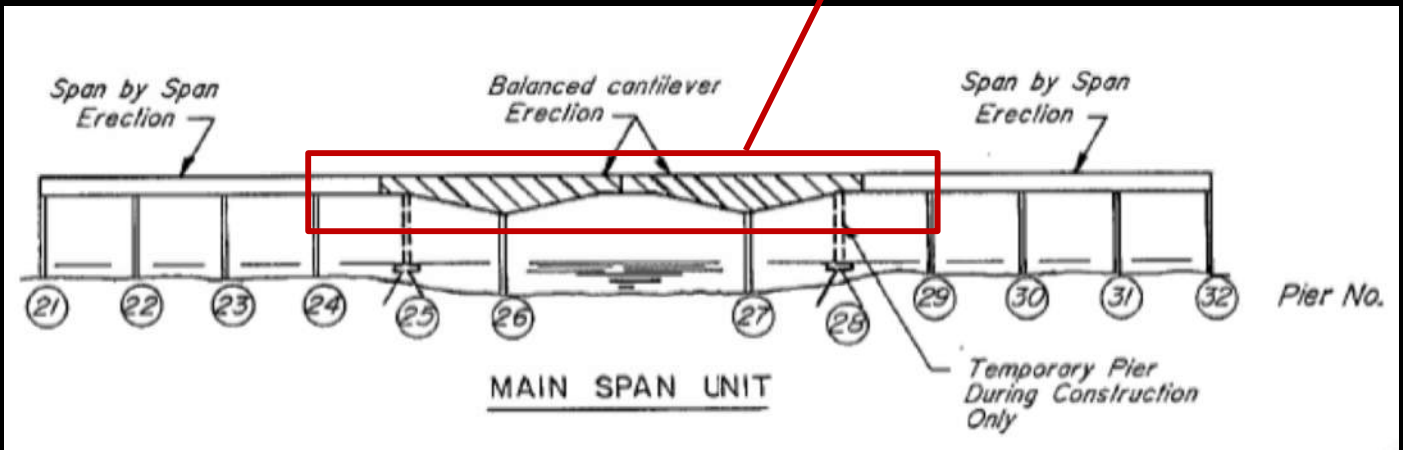
Main Span Tendon Replacement

WB structure

- **M1-R** & **M4-L** Tendons: ruptured
- **M2-L & M2-R** Tendons: completely intact, partially corroded

➔ **Different Detensioning Plans**

M1-R, M4-L, M2-L & M2-R Tendon Path



Detensioning of Ruptured M1-R and M4-L Tendons

Step 1: Installed heavy duty clamps every 4ft along the full length of the tendon

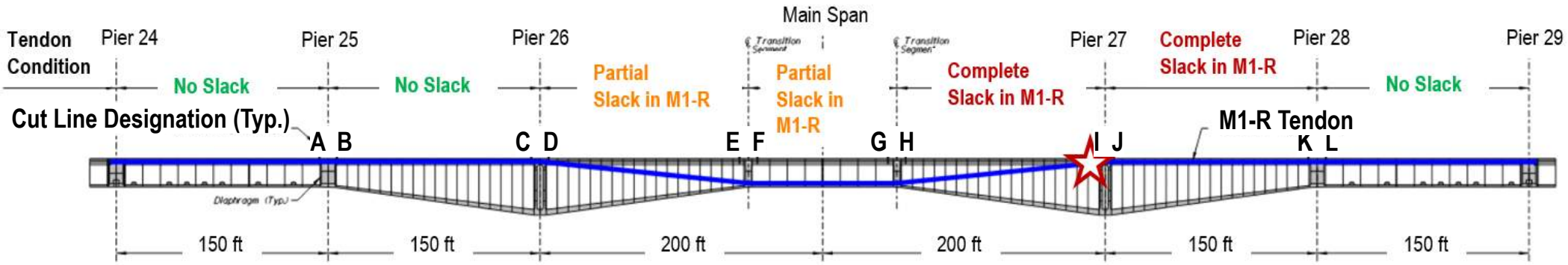
Step 2: Removed Grout at specific locations on either side of diaphragms

Step 3: Cut strands with powered cutoff saw alternately on either side of P26 to match broken strands at P27 and balance the tendon force.

Step 4: Cut strands at P28 to match P27

Step 5: Cut one strand at each point sequentially until all strands are cut

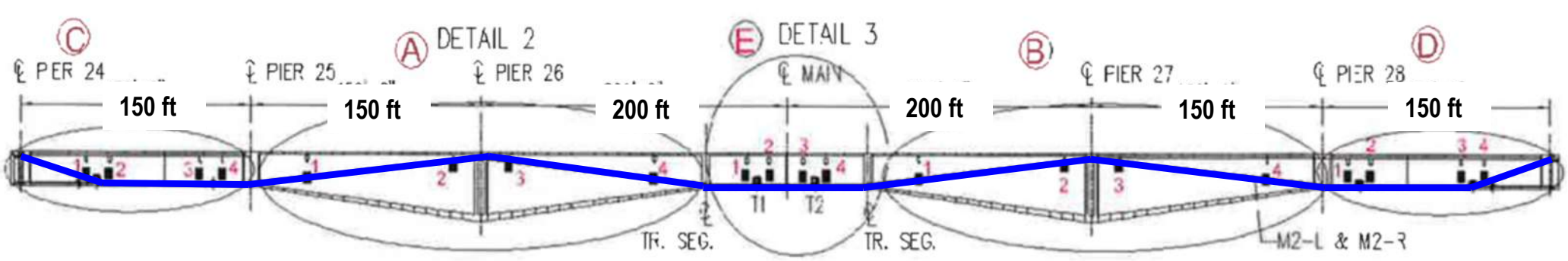
Step 6: Removed the tendons from the diaphragms by pulling the tails



Detensioning Plan for Ruptured Tendons M1-R and M4-L

Detensioning of intact M2-L & M2-R tendons

- Given the condition of the tendon, plan was developed to minimize risk
- Tendons were secured along the length of the tension to prevent whiplash
- Tendon detensioning sequence: A-B-C-D-E



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

Detensioning M2 Tendons

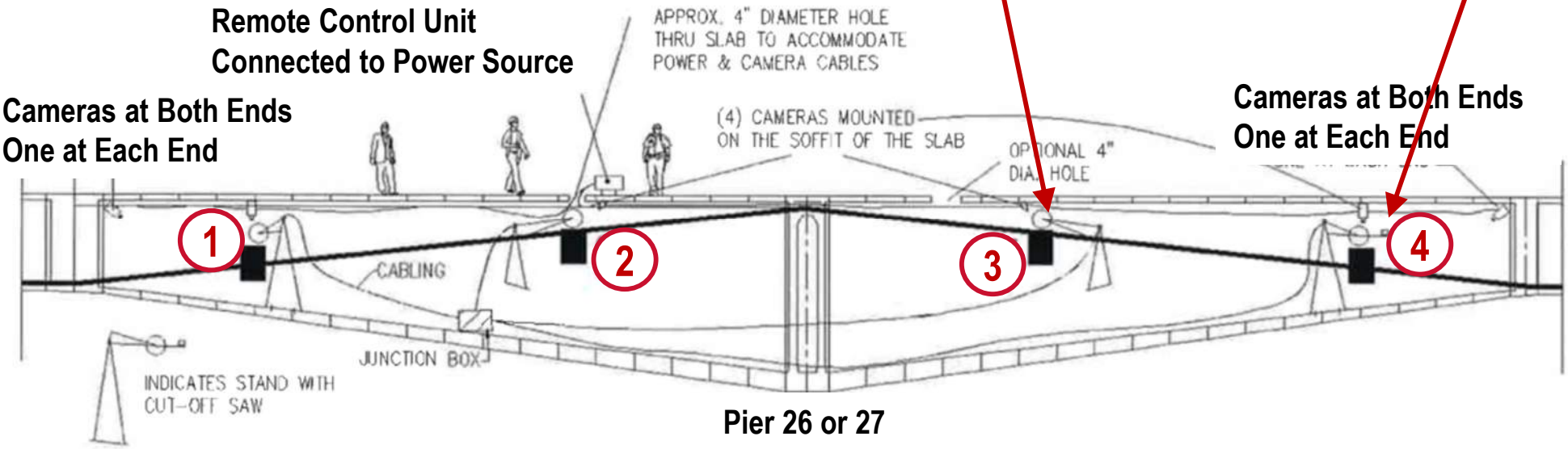
Four remote-controlled power saws

Cameras with each saw and each span

10-minute traffic closure for cutting

Remote Control Unit
Connected to Power Source

Cameras at Both Ends
One at Each End

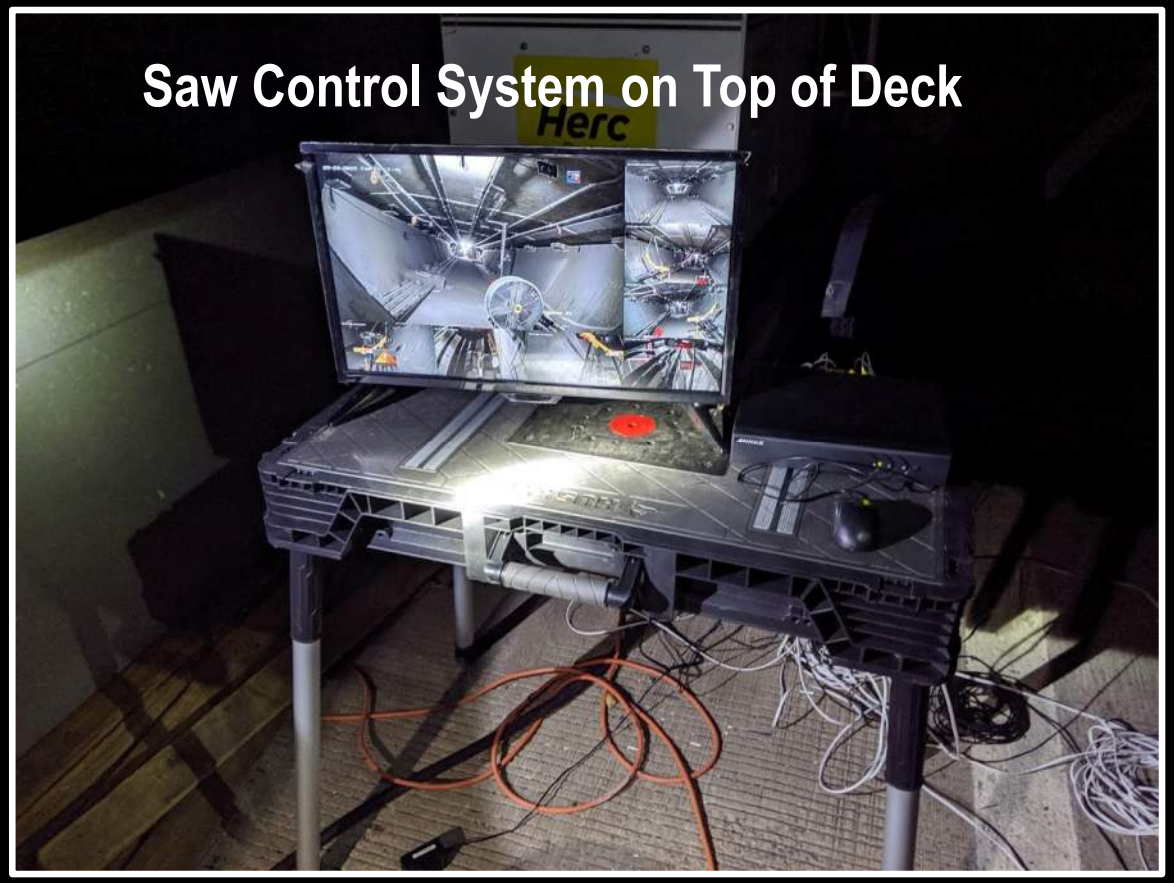


Cameras at Both Ends
One at Each End

Pier 26 or 27

Replacing M2 Tendons

M2-L and M2-R tendons were replaced one at a time

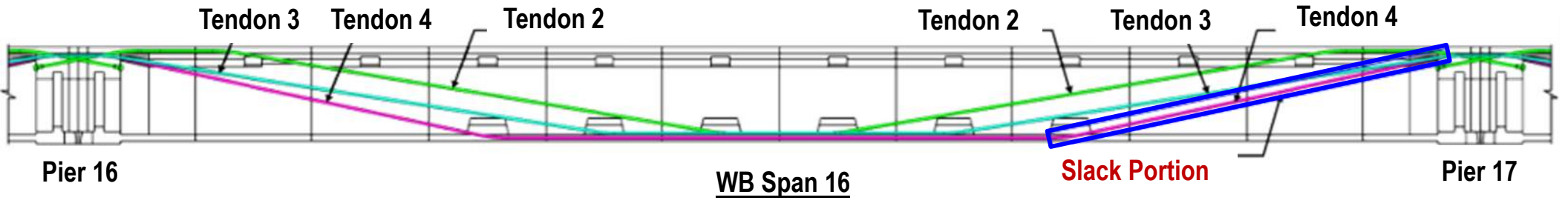


WB Span 16 Supplemental Tendons

Draped portion of **Tendon 4S** found slack

Downstation end of tendon still had tension

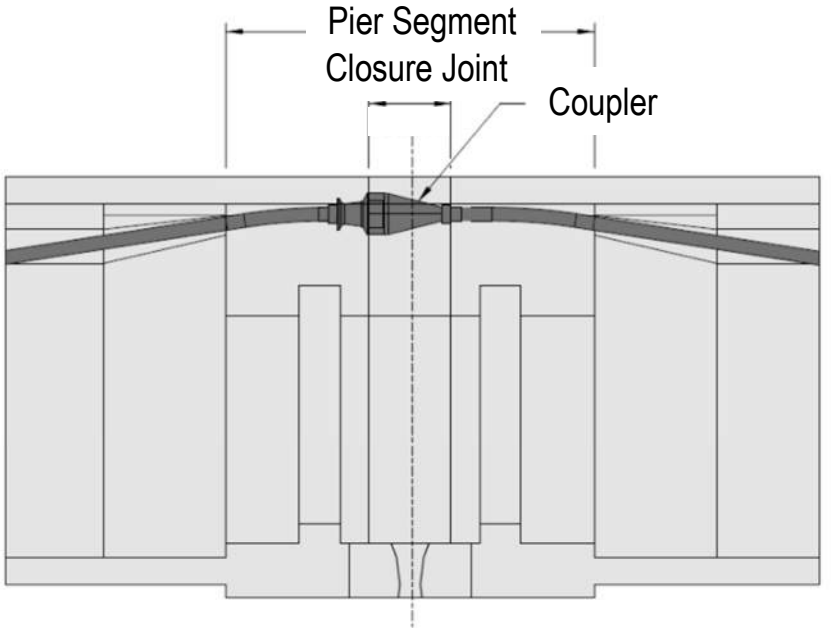
No evidence of corrosion or water infiltration of the tendon or at the diaphragm

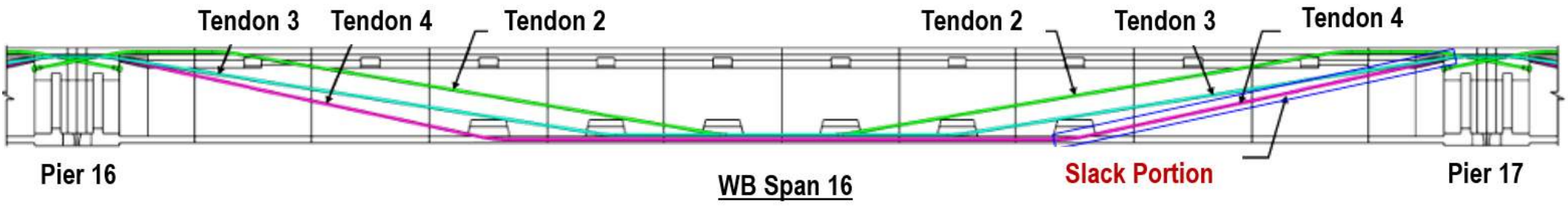


WB Span 16 Supplemental Tendons

Replacement challenges

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





WB Span 16 Supplemental Tendons

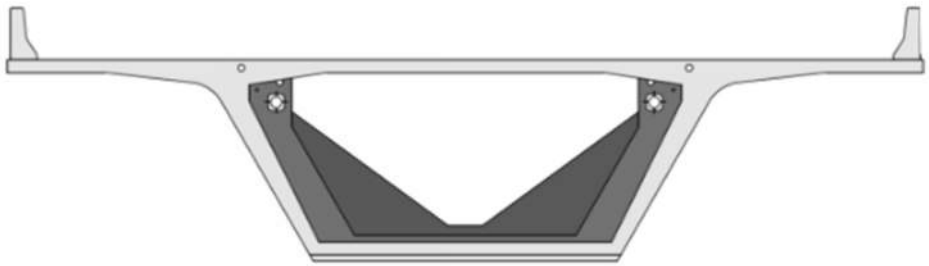
Supplemental design requirements

- Replace both shear and moment capacity
- Must not prevent remediation for other tendons

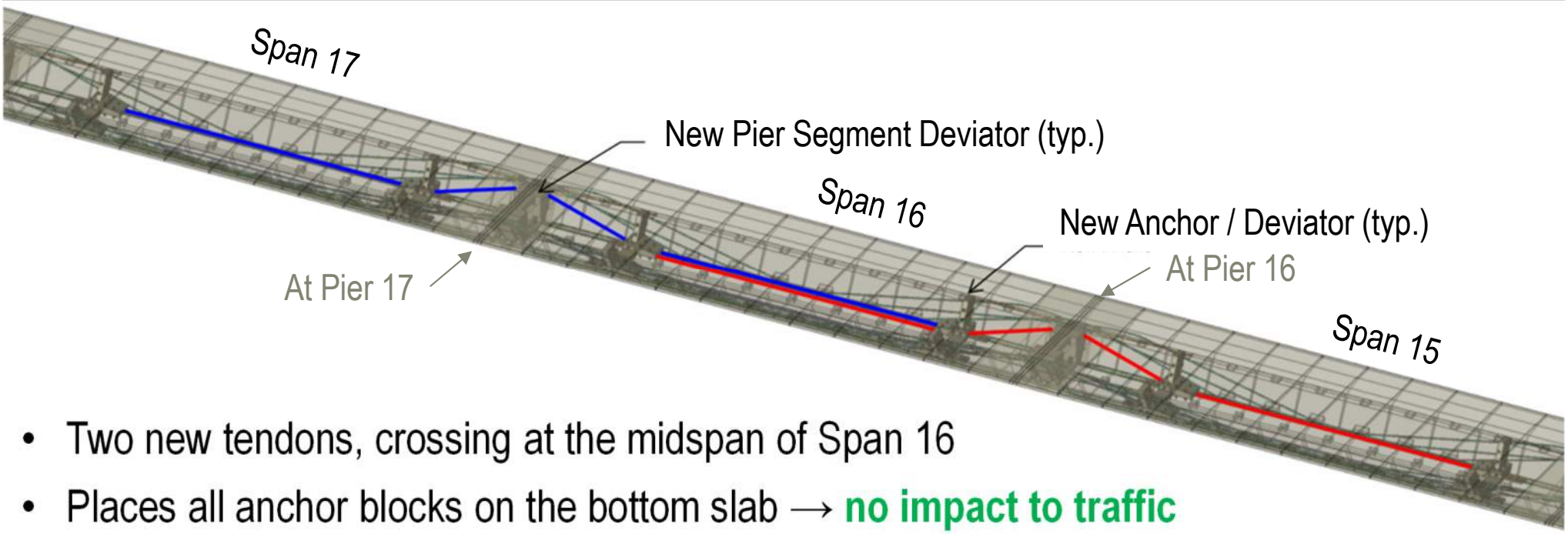
Supplemental design challenges

- Diaphragms are small and congested with reinforcing and transverse PT
- Top slab and interior haunches are relatively thin

Approach Span Diaphragm

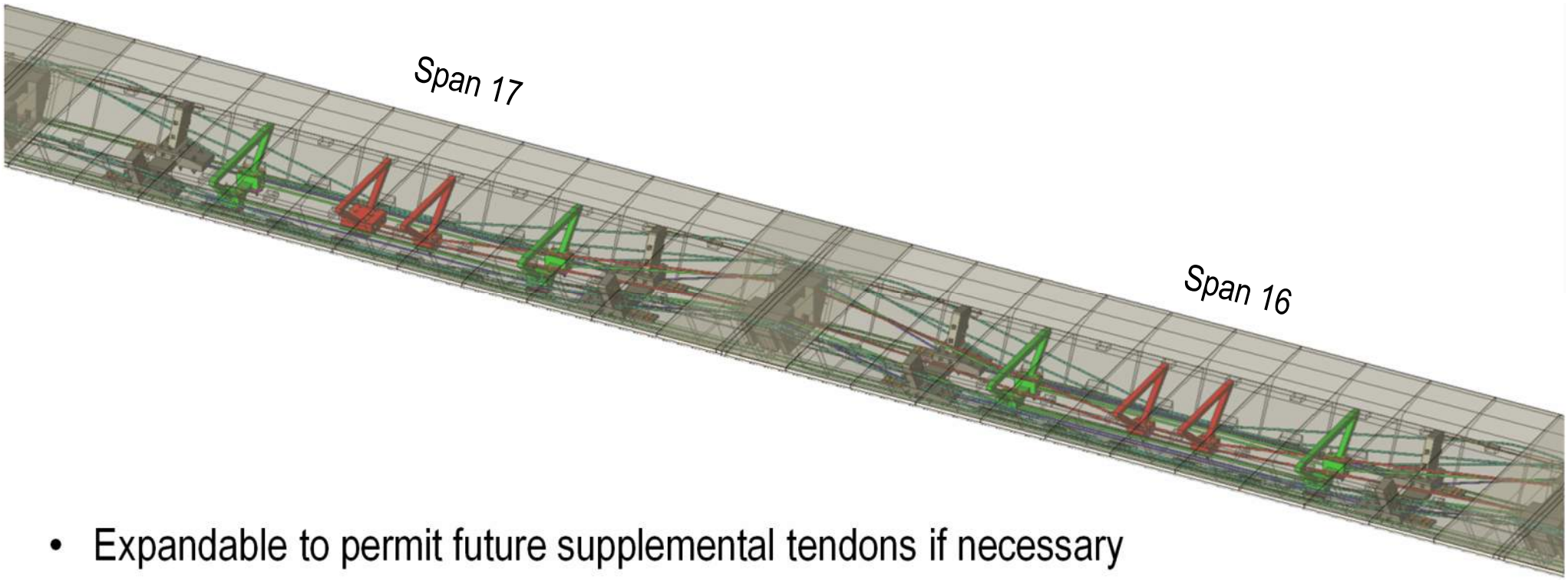


WB Span 16 Supplemental Tendons



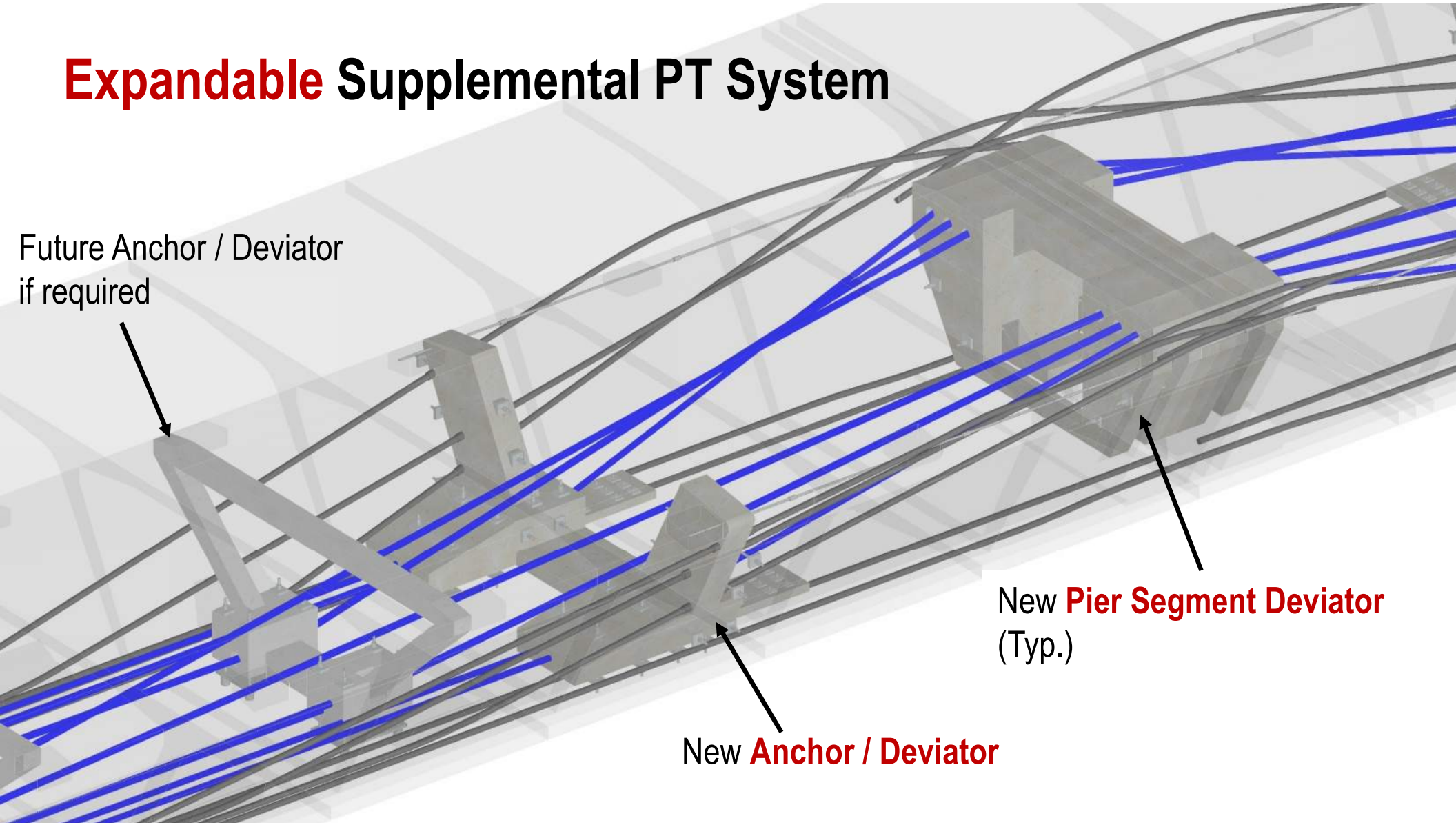
- Two new tendons, crossing at the midspan of Span 16
- Places all anchor blocks on the bottom slab → **no impact to traffic**
- Matches the Vp provided by the original tendon
- Doubles the number of strands crossing the midspan
- Provides redundancy for existing coupled tendon in adjacent span

Expandable Supplemental PT System



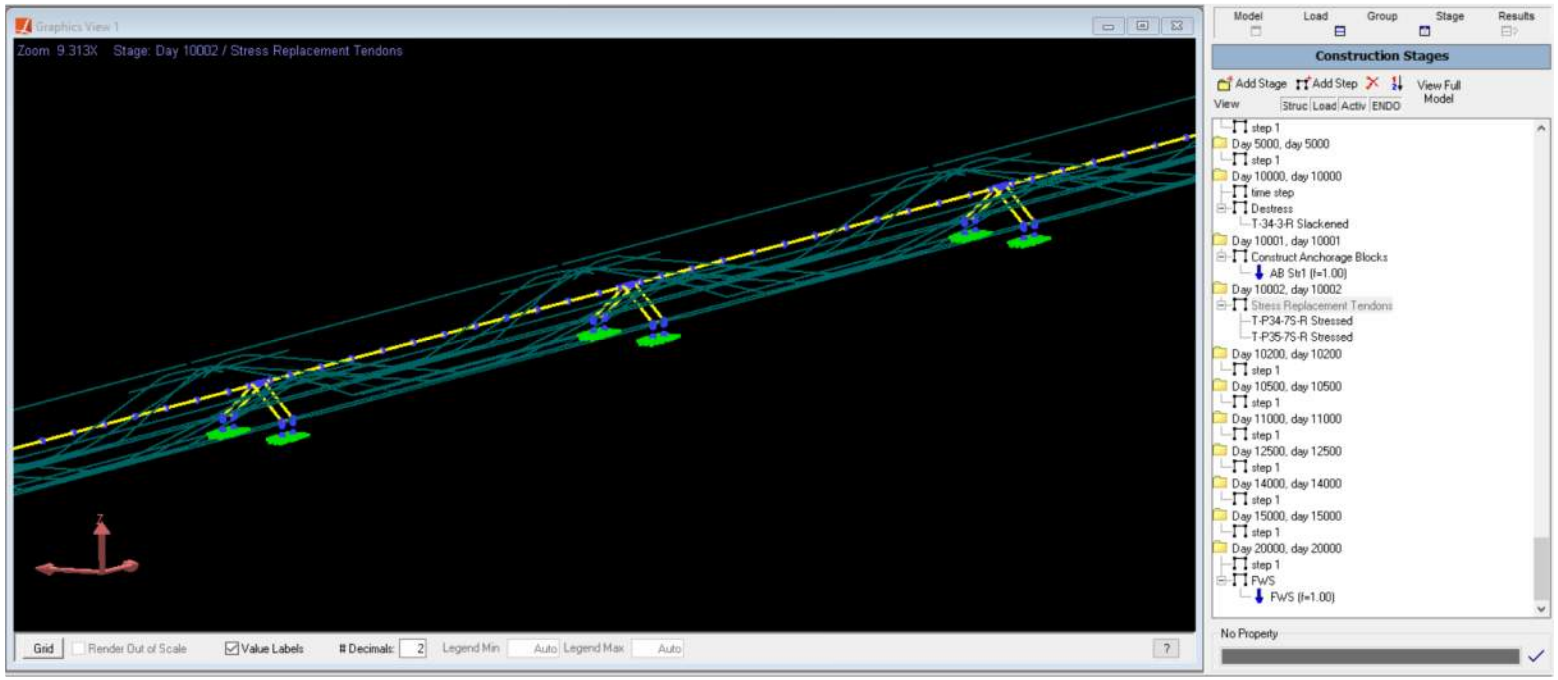
- Expandable to permit future supplemental tendons if necessary
- Deviators can accommodate replacement of all tendons in the span

Expandable Supplemental PT System



WB Span 16 Supplemental Tendons

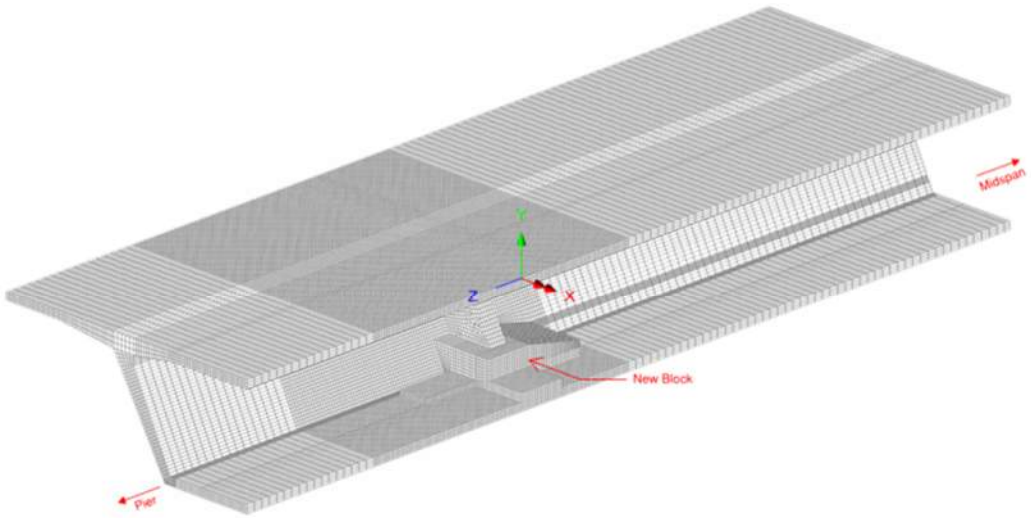
- Longitudinal and Transverse models developed in LARSA 4D
- Longitudinal design considered the controlling of:
  - Complete loss of existing tendon
  - Partial loss of existing tendon

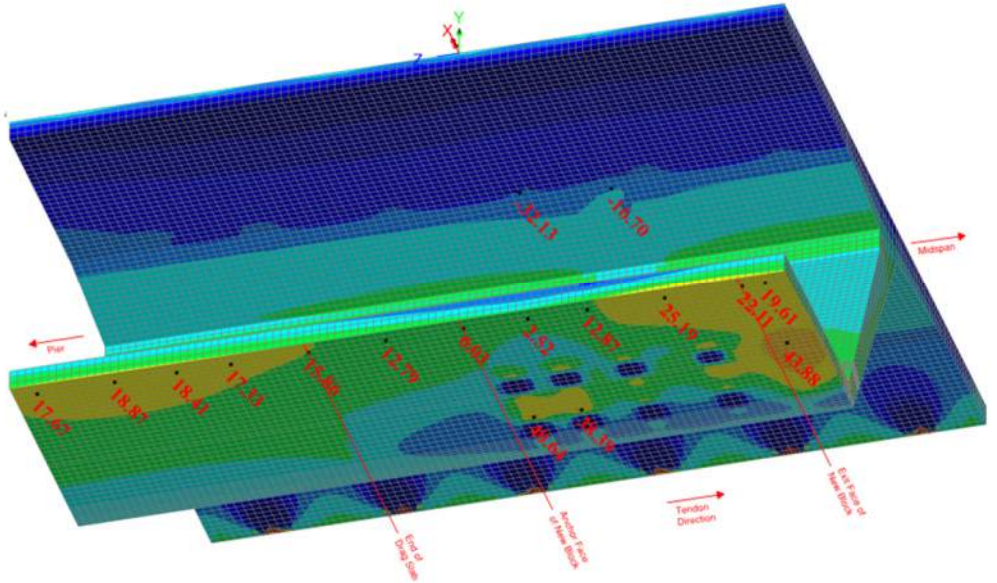


WB Span 16 Supplemental Tendons

Local effects on existing structure evaluate with Solid FEA Modeling performed in LUSAS

- Staged construction
- Initial stress state loading to match full structure analysis

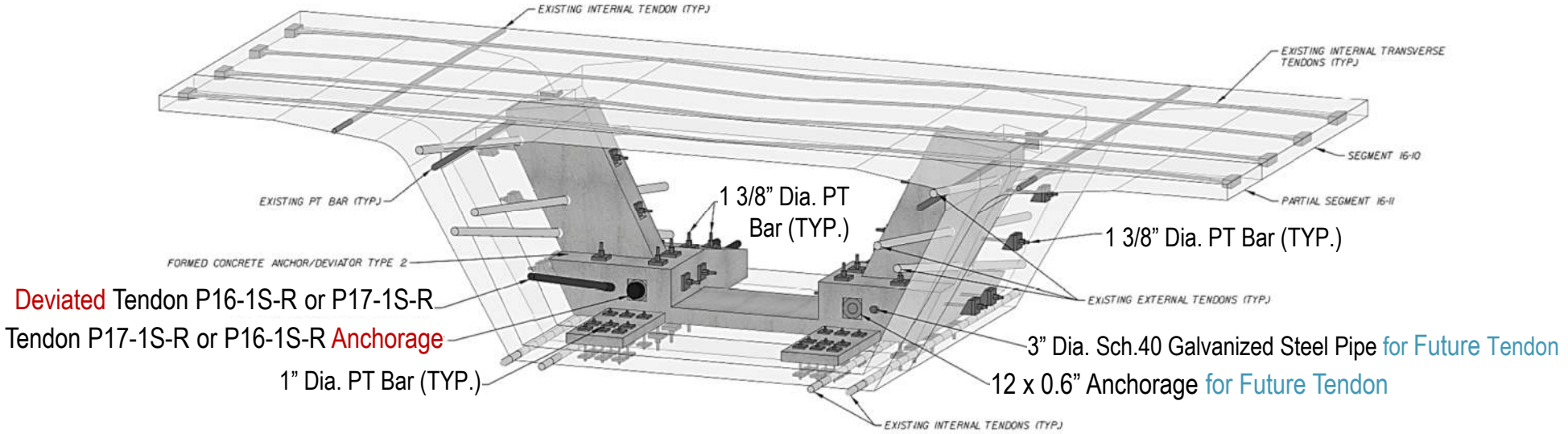




WB Span 16 Supplemental Tendons

Anchor / Deviator

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



WB Span 16 Supplemental Tendons

Anchor / Deviator

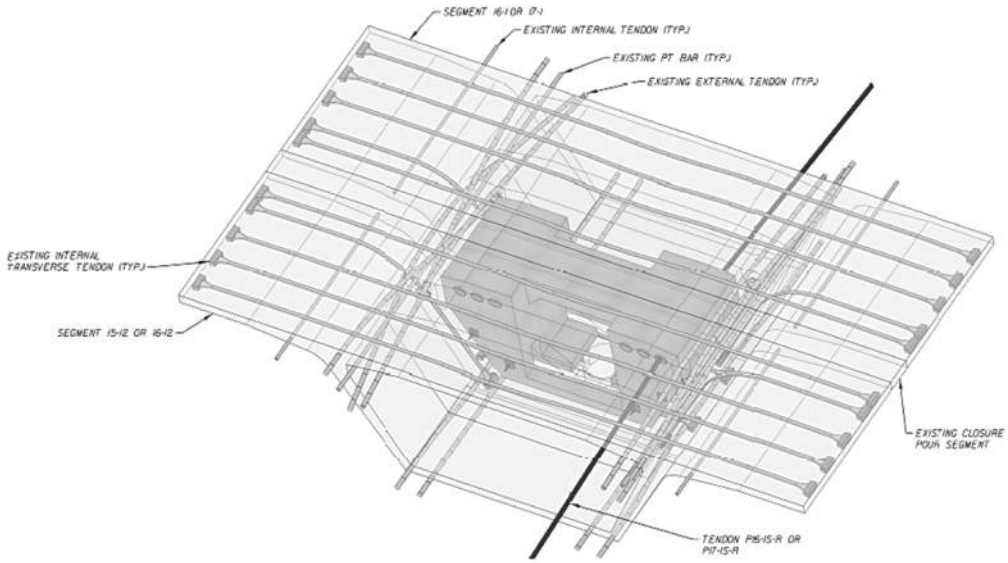
During Stressing Operations

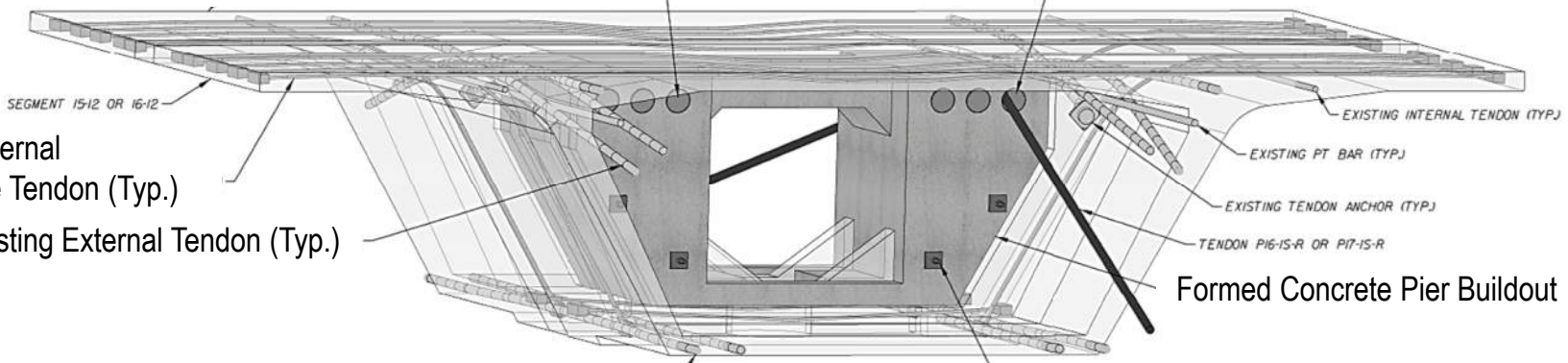
Final Condition

WB Span 16 Supplemental Tendons

Pier Segment Deviators

Designed to accommodate six tendons





WB Span 16 Supplemental Tendons

Pier Segment Deviator

WB Span 16 Supplemental Tendons

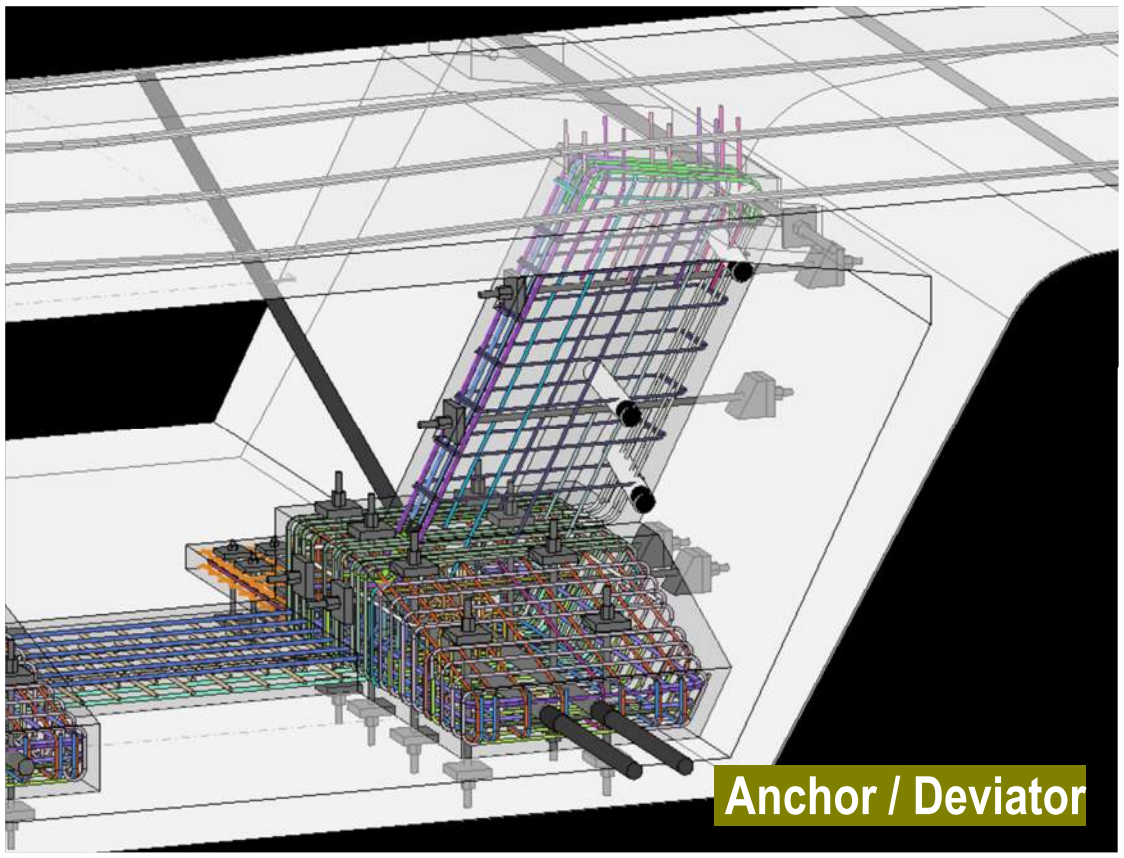
Other Details

Span 16 Stressing – Fit like a glove

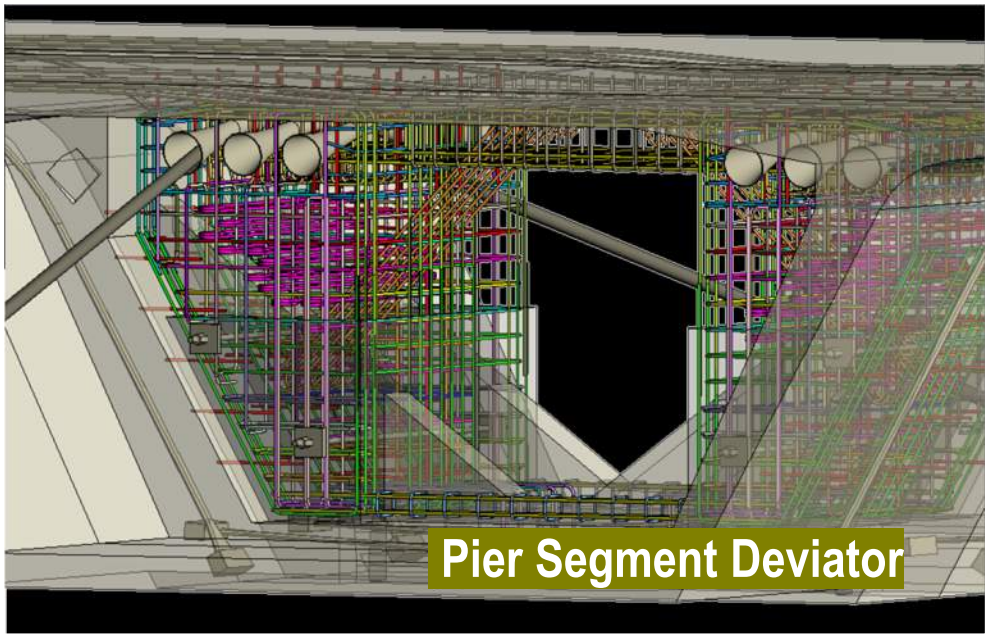
CFRP reinforcing at new access opening

WB Span 16 Supplemental Tendons

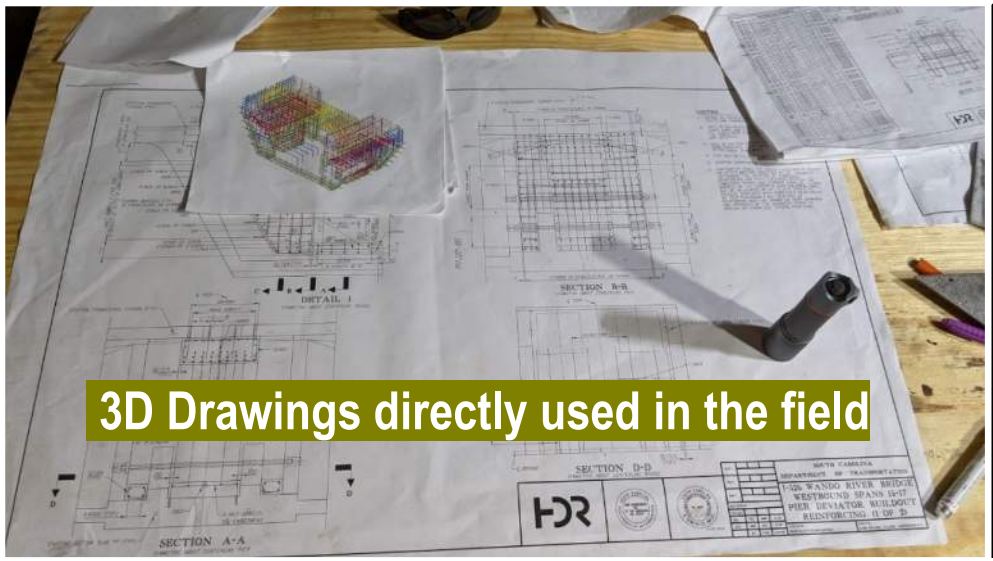
3D Drawings



Anchor / Deviator



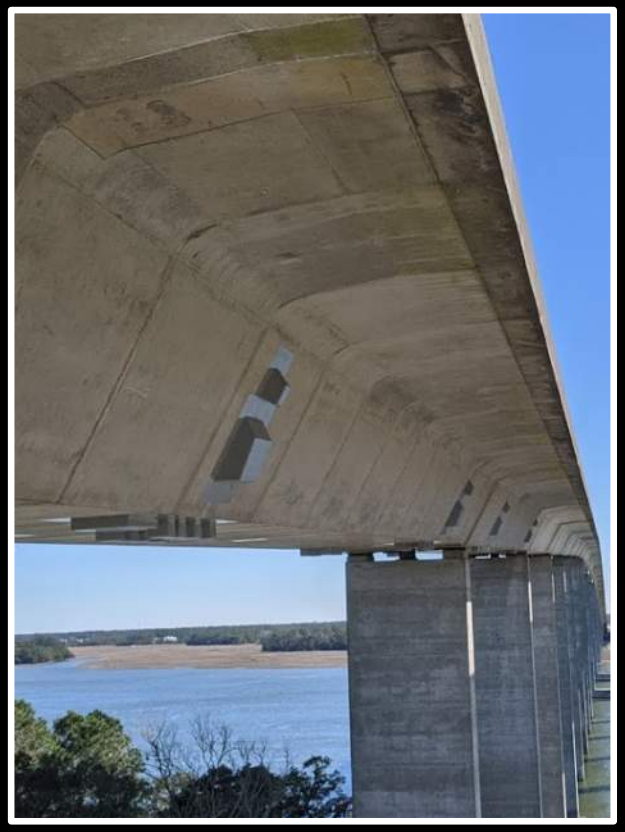
Pier Segment Deviator



3D Drawings directly used in the field

WB Span 16 Supplemental Tendons

Outside the box



N-2 Missouri River Bridge

Nebraska City, NE

Post-Tensioning Tendon Repairs

Structure Overview

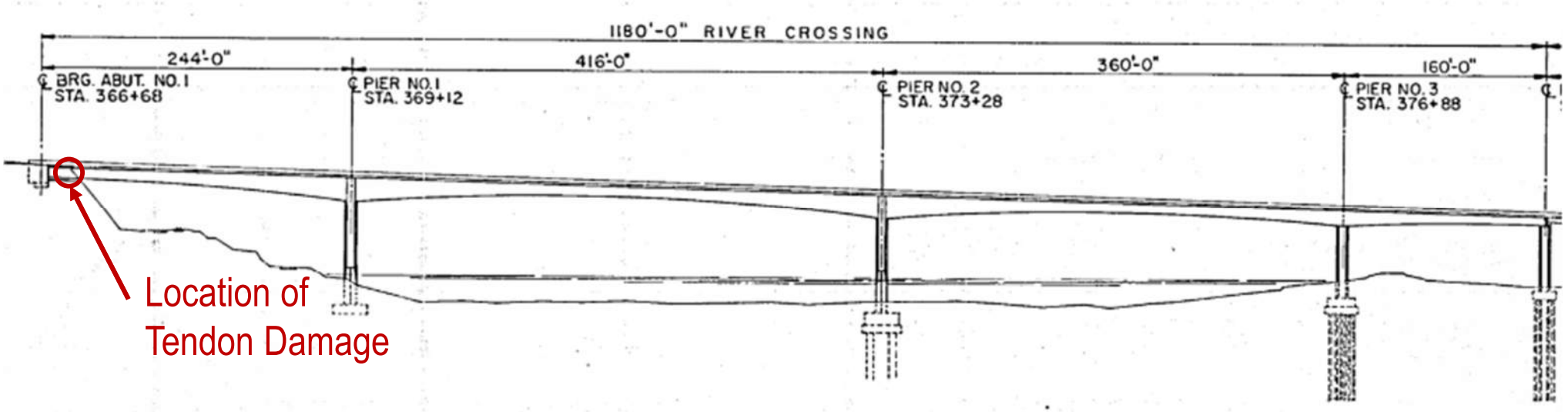
N-2 Missouri River Bridge

N-2 Missouri River Bridge

Overview

Main Span Unit

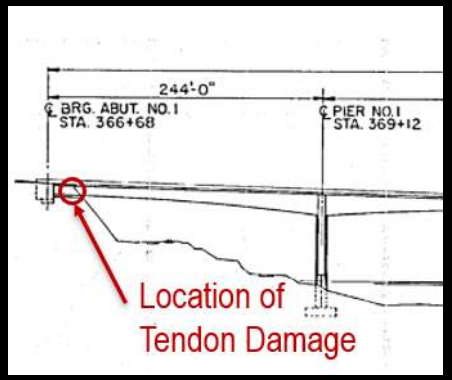
- Constructed in 1986
- Balanced Cantilever Construction
- 1,180 ft Long Cast-in-Place Post-Tensioned Segmental Bridge



July 2021…

Corroded PT Tendons in Bottom Slab in main span unit

- Rainwater Permeated the Bottom Slab Over Time, Corroding the Tendons
- **Very Localized**; No Further Damage Found Along Tendons



July 2021…

- The Bridge was reopened to legal trucks after 3 days.
- Two of the four lanes remained closed until completion of the rehab project.

Missouri River bridge near Nebraska City closed to truck traffic for 'rehab project'

WOWT 6 News Live at 10

By Taleisha Newbill and Tara Campbell
Published: Jul. 26, 2021 at 4:30 PM EDT

Highway 2 bridge over Missouri River reopens to truck traffic

By 6 News staff reports
Published: Jul. 29, 2021 at 7:58 PM EDT

Repair Phase

N-2 Missouri River Bridge

Supplemental PT Design

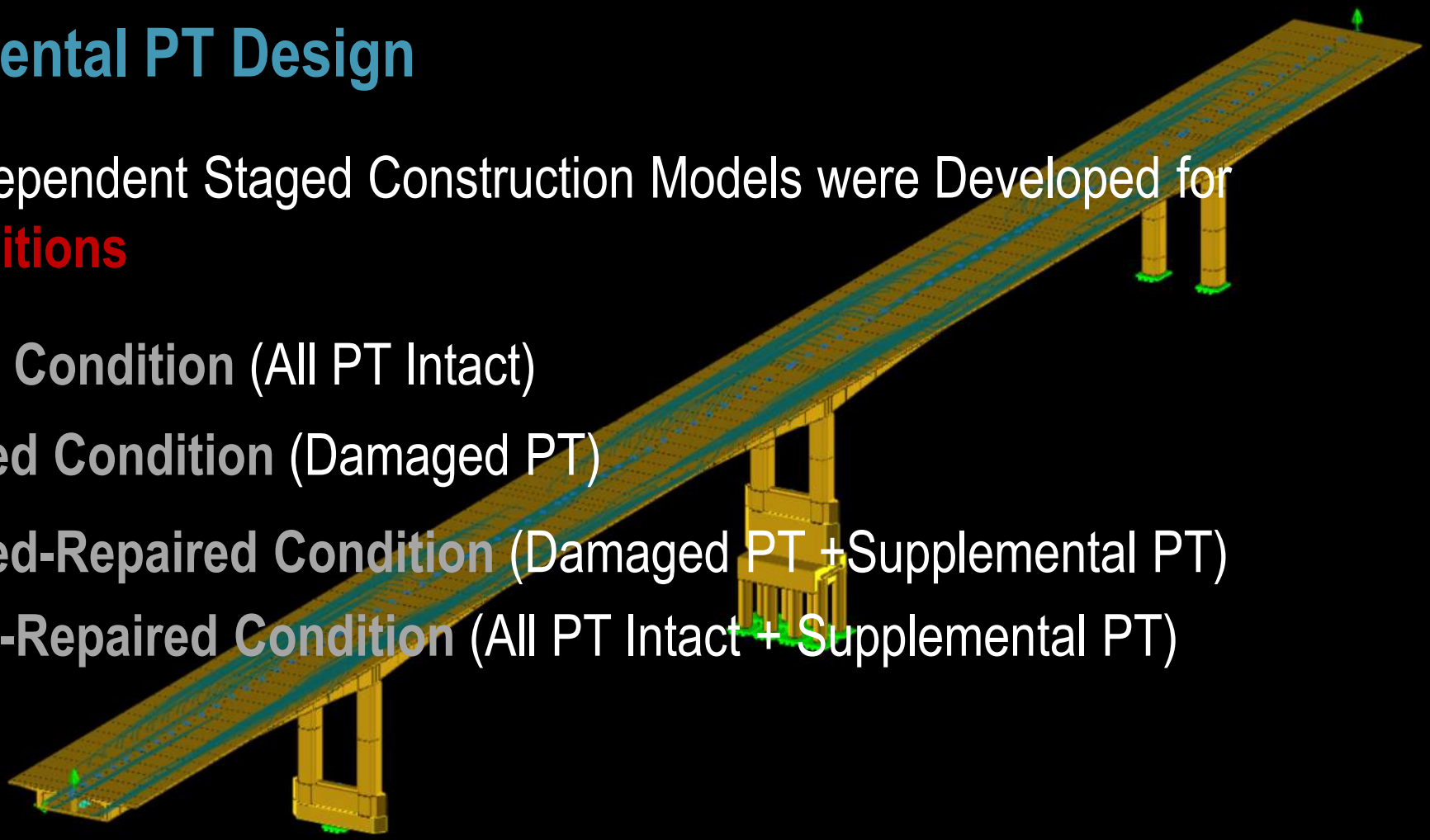
3D Time-Dependent Staged Construction Models were Developed for **Four Conditions**

1 - Original Condition (All PT Intact)

2 - Degraded Condition (Damaged PT)

3 - Degraded-Repaired Condition (Damaged PT +Supplemental PT)

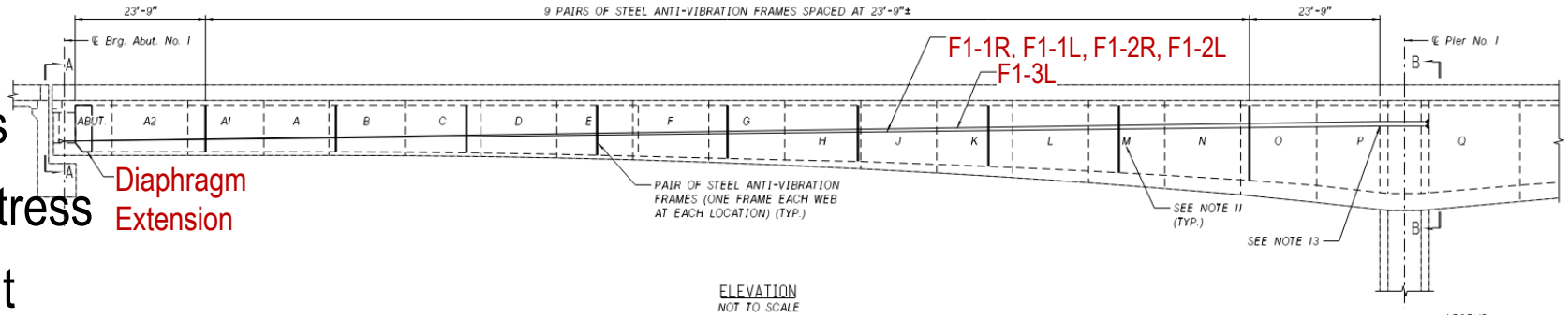
4 - Original-Repaired Condition (All PT Intact + Supplemental PT)



Supplemental PT Design

Design Checks

- Normal Stresses
- Web Principal Stress
- Ultimate Moment

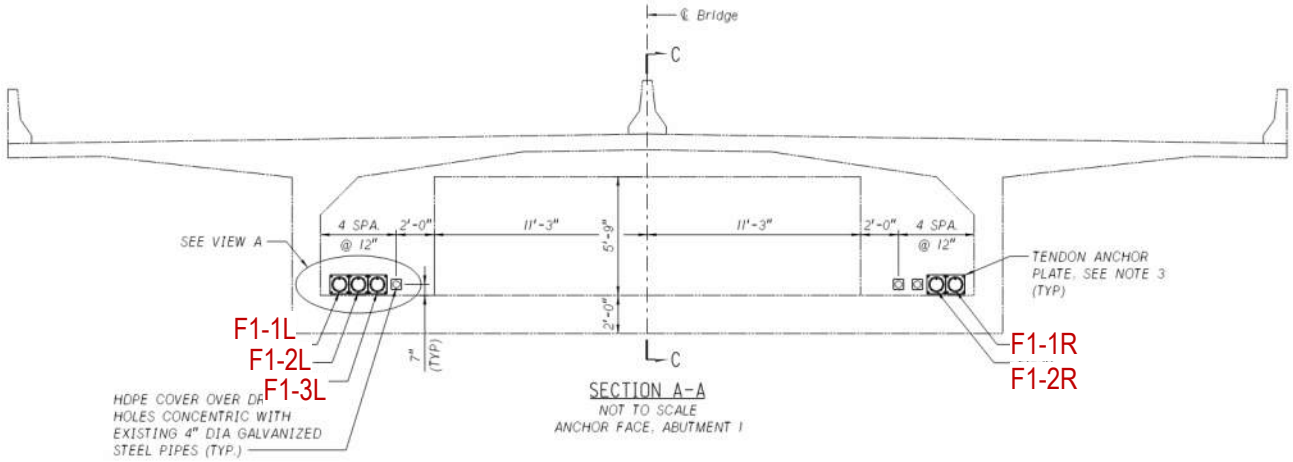


Supplemental PT System

- Asymmetric PT Configuration to Counter Asymmetry of Existing Tendons Due to Damaged PT

  3 – 12 Strand Tendons North Web

  2 – 12 Strand Tendons South Web

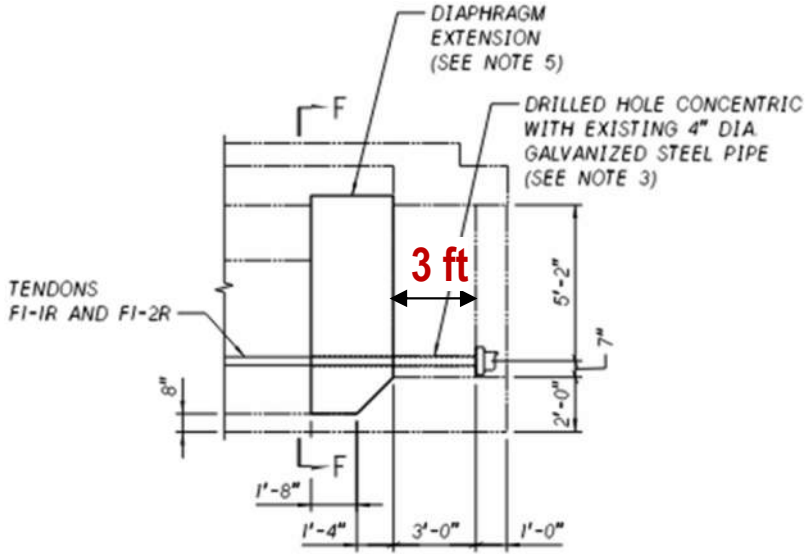


Evaluation of Existing Diaphragms

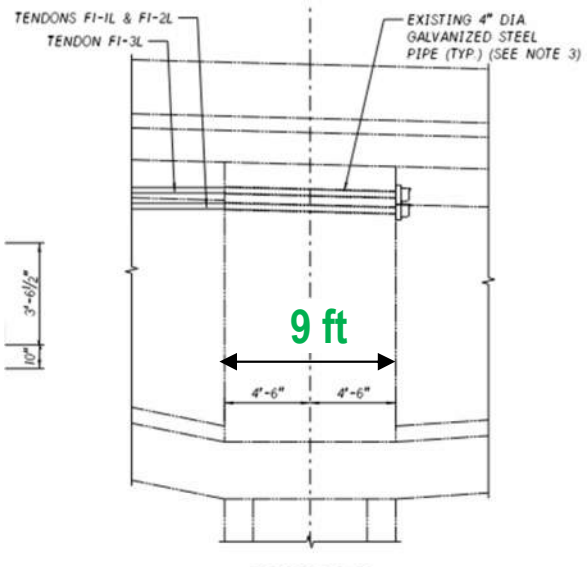
- Original Bridge Design Included Accommodations for Future Tendons
- Diaphragms Checked to Ensure Adequate Capacity for the Supplemental Tendons

  Abutment 1 Diaphragm – Not Sufficient

  Pier 1 Segment Diaphragm – Sufficient



Abutment 1 Diaphragm



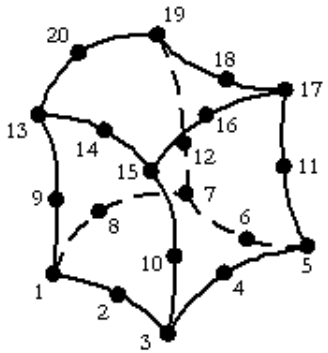
Pier 1 Diaphragm

Evaluation of Existing Abutment 1 Diaphragm

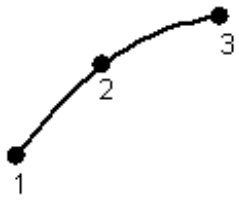
3D Solid Element Models in LUSAS

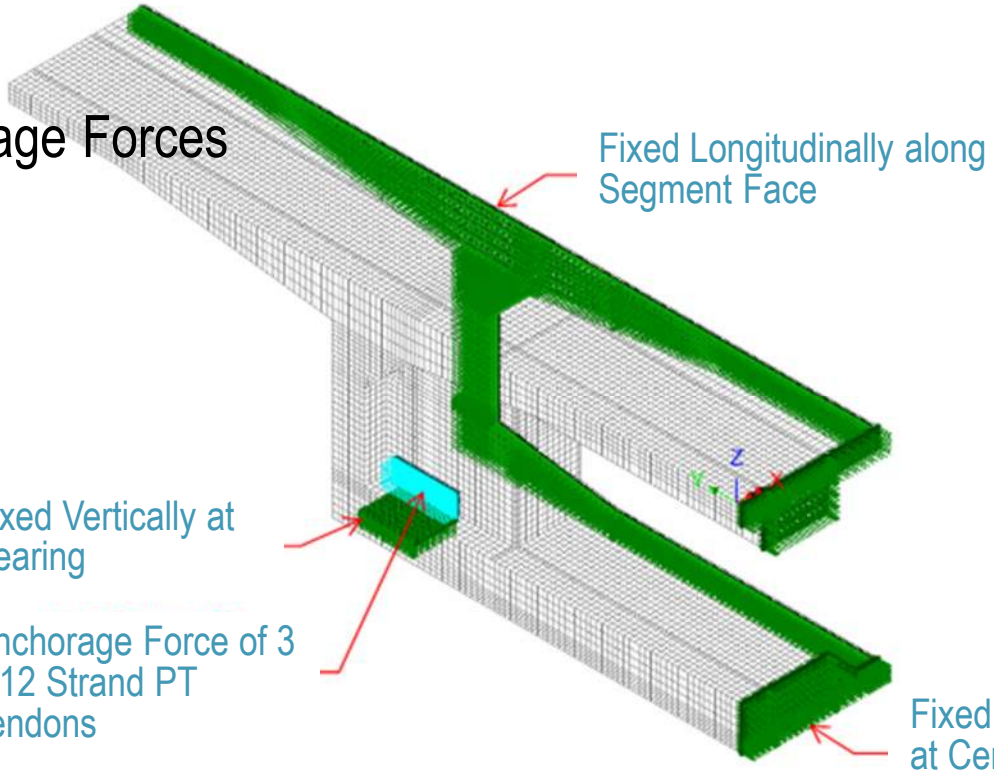
- Discrete Patch Loads for PT Anchorage Forces
- Boundary Conditions
- Elements

HX20 (concrete)



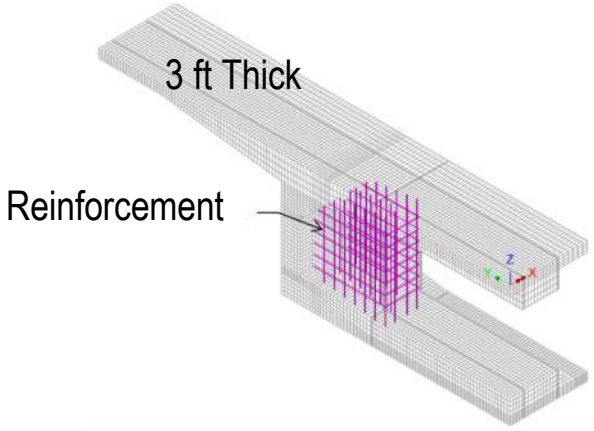
BRS3 (rebar)

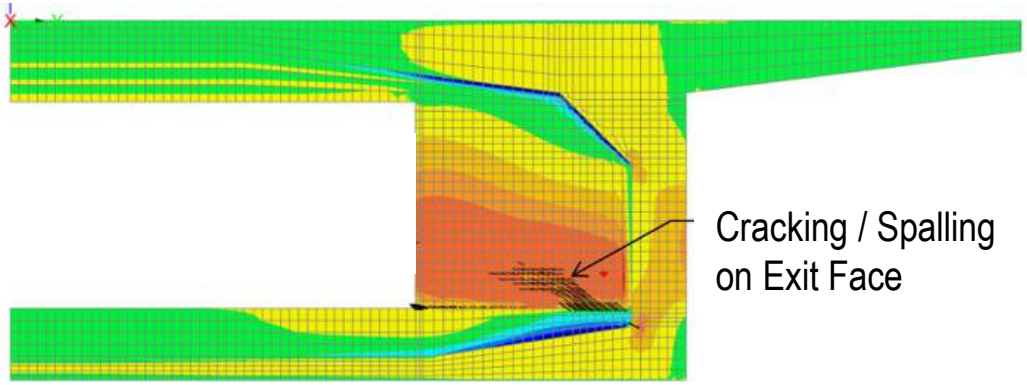




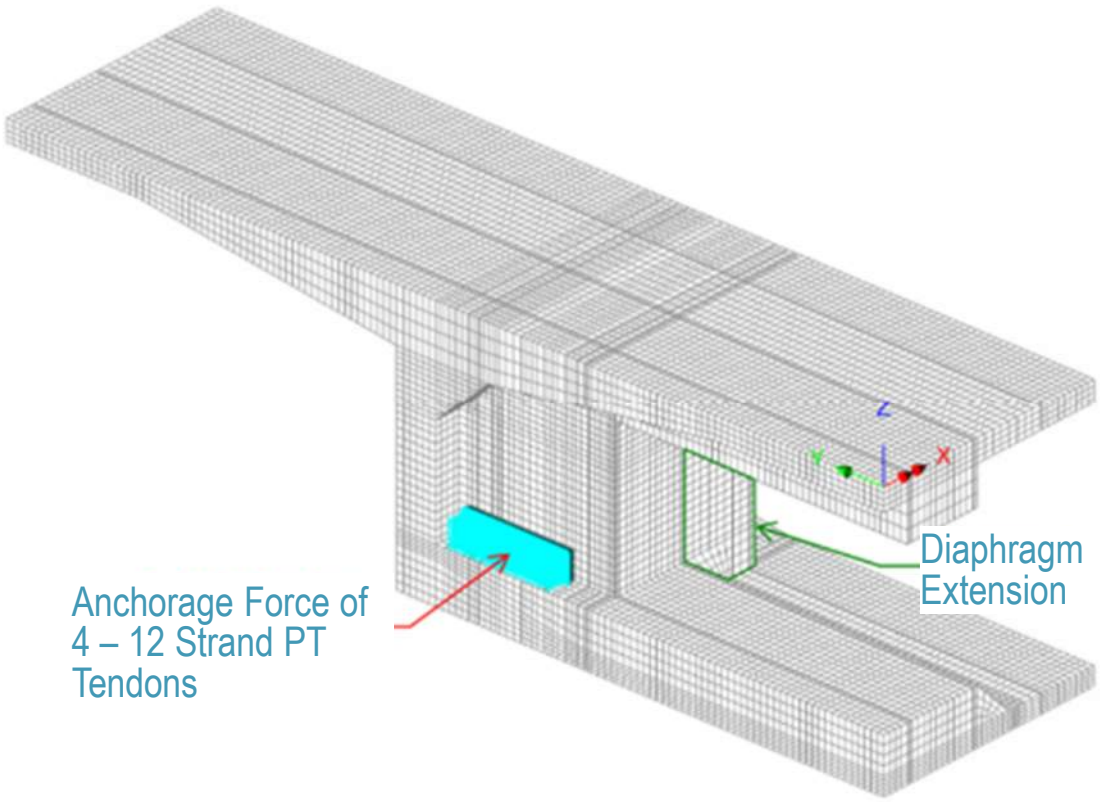
Evaluation of Existing Abutment 1 Diaphragm

	Linear Elastic Model	Plastic-Crack Model with Discrete Rebars
Purpose	To calculate a tensile force / amount of reinforcement required by the tie force.	To see how forces redistribute once cracking occurs and to calculate a tensile force / amount of reinforcement required by the tie force.
Conclusions	The reinforcement required by the tie force is greater than the reinforcement in the existing diaphragm.	The model predicted heavy cracking on the exit face of the diaphragm. We needed to extend the diaphragm.





Abutment 1 Diaphragm Extension Design



Modified the Existing Abutment Diaphragm Models to Incorporate **the Diaphragm Extension**

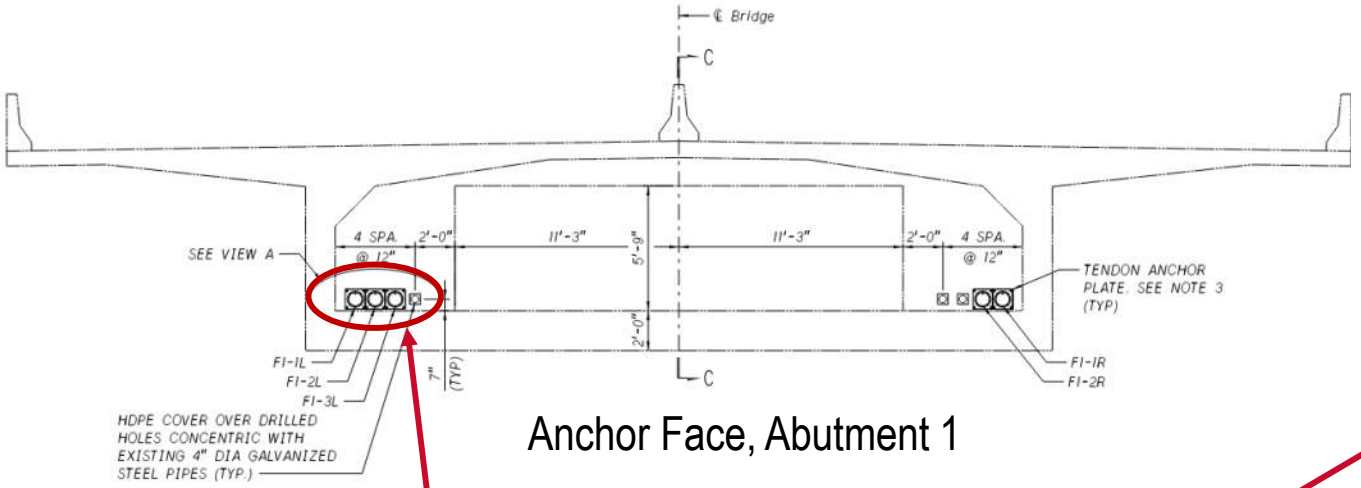
- Diaphragm Extended 3’-0”
- Designed Diaphragm Extension for “Future Tendons” (Used 4-12 Strand Tendons in the Model)

Post-Installed Supplemental Tendon System – Abutment Diaphragm

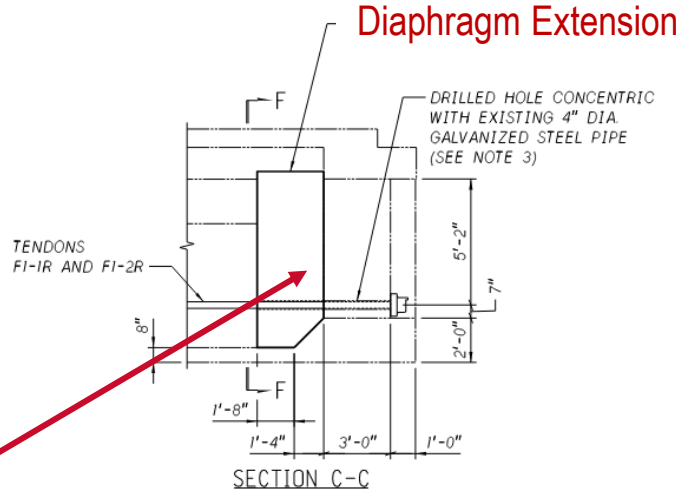
Diaphragm Extension – Rebar Cage

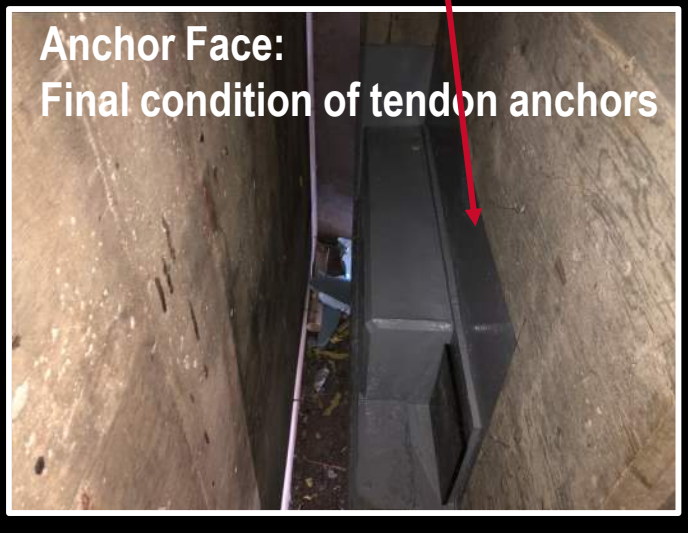
Completed Diaphragm Extension

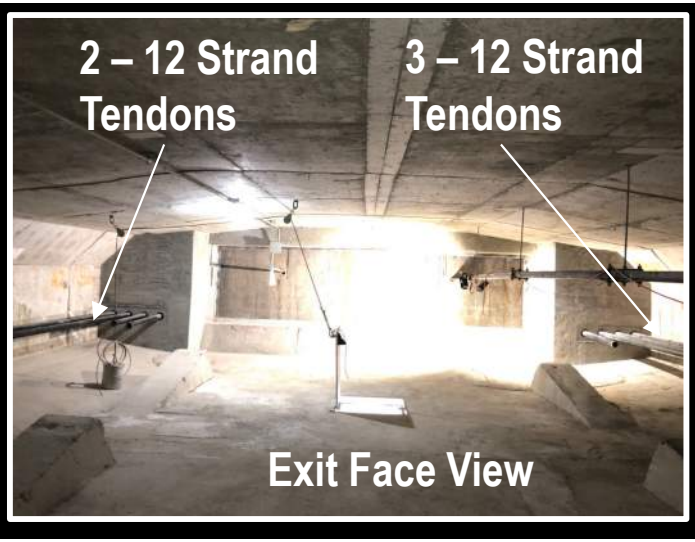
Post-Installed Supplemental Tendon System - Abutment Diaphragm



Anchor Face, Abutment 1







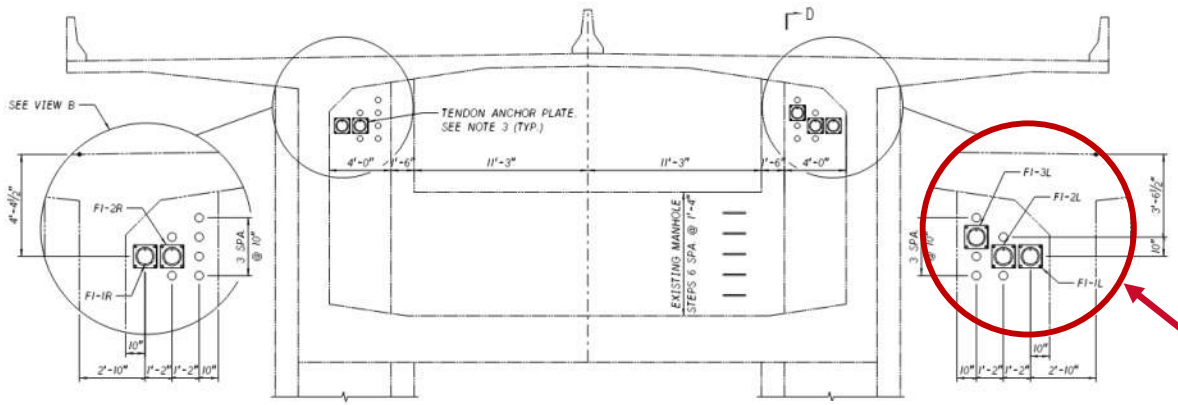
Post-Installed Supplemental Tendon System

Post-Installed Supplemental Tendon System

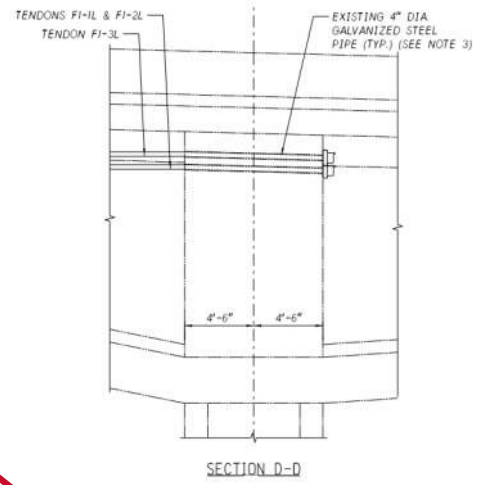
Pier Segment Diaphragm

Tendon Stressing at Pier 1 Diaphragm

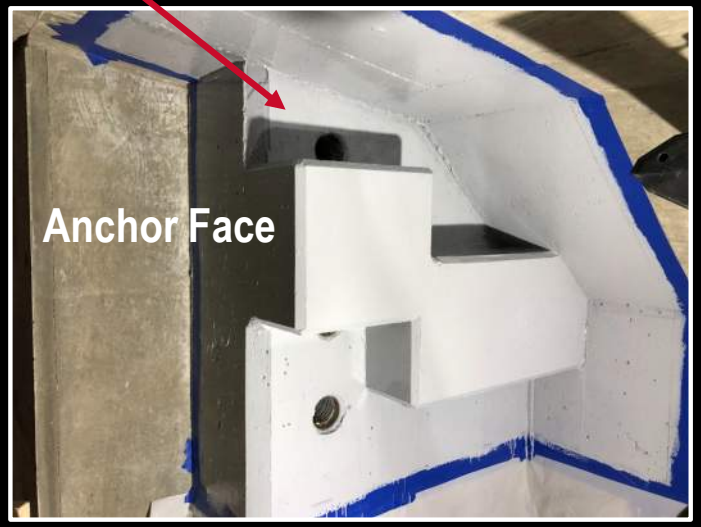
Post-Installed Supplemental Tendon System - Pier Segment Diaphragm



Anchor Face, Pier 1 Diaphragm



SECTION D-D



Post-Tensioning Tendon Repairs of Two Segmental Concrete Bridges

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IBC 22-50

KEYWORDS: Post-Tensioning, Rehabilitation, Finite Element Modeling

ABSTRACT: This paper presents the design and construction of post-tensioning tendon repairs for two segmental concrete bridges. The design for both structures utilized a combination of 3D time-dependent staged-construction finite element beam models to evaluate overall behavior and non-linear finite element solid models to evaluate local effects. The repairs included detensioning the damaged tendons and installation of supplemental external tendons, construction of expandable post-tensioning systems with post-installed anchors and deviators, and the extension of an existing end diaphragm.

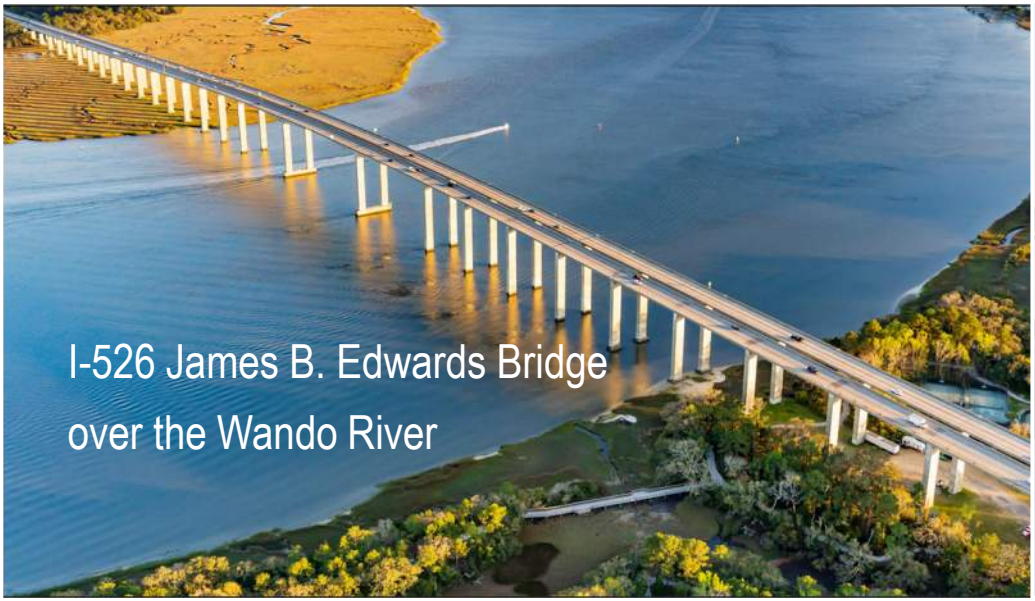
Two Key Takeaways

- Both Bridges were built in the 1980s. Significant improvement in the industry since these bridges were constructed (specifications, materials, and industry-standard training).
- Replaceable tendon details should be considered whenever feasible, but there are methods at add PT if necessary.

Acknowledgments

I-526 James B. Edwards Bridge

N-2 Missouri River Bridge



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QUESTIONS?