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Collapse of the Fern Hollow Bridge

Pittsburgh, Pennsylvania
January 28, 2022

Virtual Board Meeting Staff Participants

Brian Curtis	Deputy Managing Director (MD)
Kris Poland, PhD	Deputy Director, Office of Highway Safety (OHS)
Meg Sweeney, PhD	Project Manager (OHS)
Dennis Collins	Investigator-in-Charge (OHS)
Steve Prouty, PE	Structural Engineer (OHS)
Dan Walsh, PE	Structural Engineer (OHS)
Adrienne Lamm	Materials Engineer (RE)
Eric Gregson	Reconstruction/Drone Operations (OHS)

Virtual Board Meeting Staff Participants

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Carl Perkins	Management Information Specialist (MD)

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Collapse of the Fern Hollow Bridge
January 28, 2022

Dennis J. Collins
Investigator-in-Charge

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Collapse of the Fern Hollow Bridge

Pittsburgh, Pennsylvania
January 28, 2022

Additional Collapse Details

- Dark with light snow
- All injured persons transported by 8:26 a.m.
- Precautionary evacuation due to gas main but no fire or explosion
- Emergency response excluded as a factor

On-Scene and Investigative Staff

• Jennifer Homendy	Chair
• Erik Strickland	Executive Officer
• Dennis Collins	Investigator-in-Charge
• Steve Prouty, PE	Structural Engineer
• Adrienne Lamm	Materials Engineer
• Eric Gregson	Reconstruction/Drone Operations
• Rob Molloy, PhD	Director, Office of Highway Safety

On-Scene and Investigative Staff (continued)

• Meg Sweeney, PhD	Project Manager
• Eric Weiss	Chief, Media Relations
• Rolando Garcia	Assistant Advisor, Special Operations
• James Anderson	Audio Visual Production Specialist
• David Pereira	Evidence Management Specialist
• James Gunter	Information Technology Specialist

Report Development Staff

• Dan Walsh, PE	Structural Engineer
• Mike Brokos	Technical Writer/Editor
• Alice Park	Animation
• Christy Spangler	Graphics
• Jennifer Beatty	Graphics
• Deven Chen	Recorder Specialist
• Julie Perrot	Safety Recommendation Specialist

Parties

- Federal Highway Administration (FHWA)
- Pennsylvania Department of Transportation (PennDOT)
- City of Pittsburgh
- Pittsburgh Regional Transit (formerly Port Authority of Allegheny County)

Safety Issues

- Repeated lack of action on recommendations from inspections
- Bridge inspection program failures
  - Noncompliance with guidance
  - Failure to identify fracture-critical members
  - Inaccurate bridge load rating calculations
- Insufficient oversight at city, state, and federal level

Staff Presentations

- Adrienne Lamm, Materials Engineer
  - Uncoated weathering steel corrosion, steel testing, and finite element modeling
- Steve Prouty, PE, Structural Engineer
  - Fern Hollow Bridge inspection reports, quality of inspections, fracture-critical member inspection plans
- Dan Walsh, PE, Structural Engineer
  - Load ratings, asphalt wearing surface, oversight of inspections by the City of Pittsburgh, PennDOT, and FHWA

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Corrosion, Materials Testing, and Cause of Collapse

Adrienne Lamm, Materials Engineer

Overview

- Observation and documentation of corrosion
- Results of material properties testing
- Finite element (FE) model

Uncoated Weathering Steel (UWS)

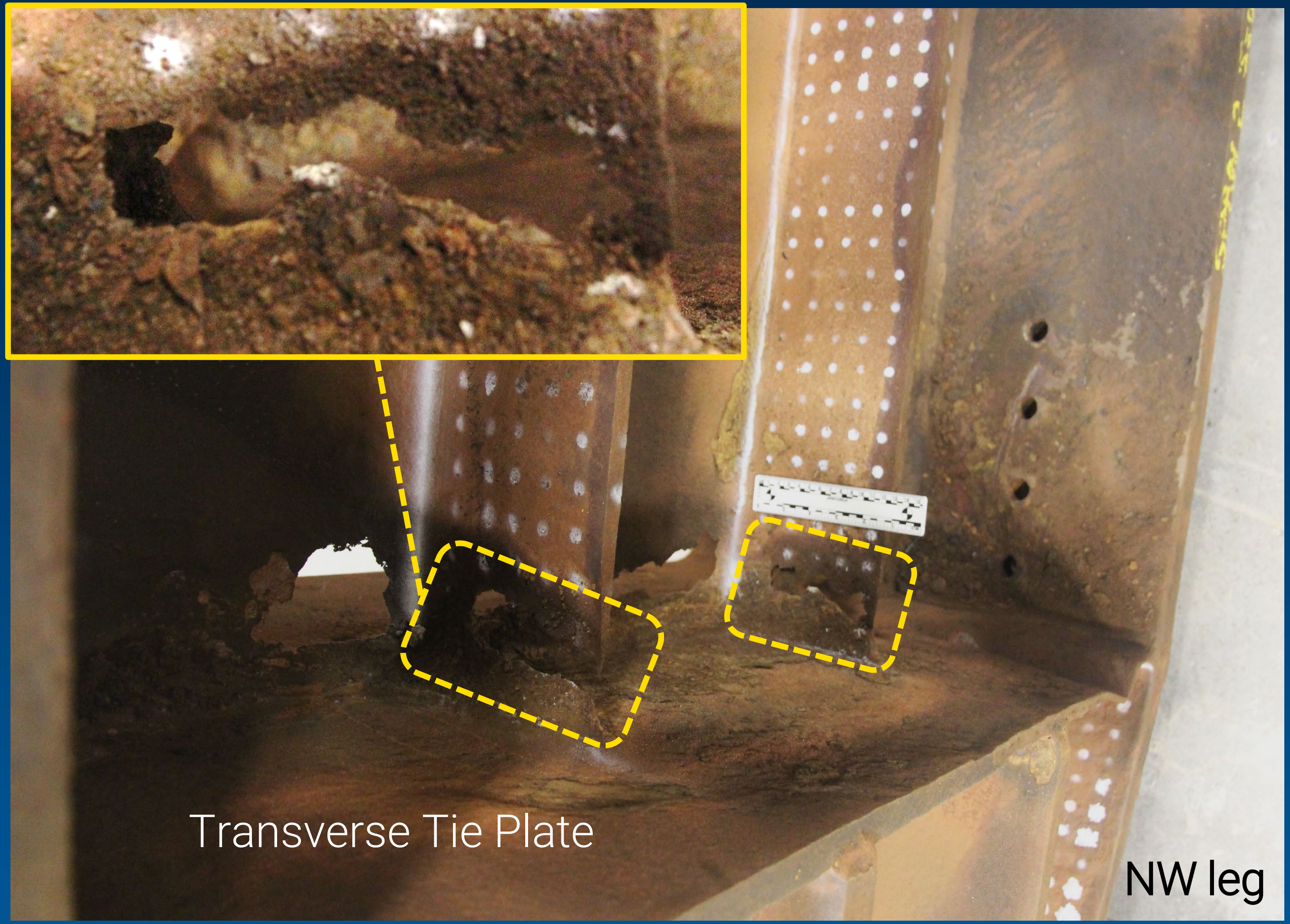
- Developed in 1910s, used since the 1960s
- High strength, low-alloy steel
- Forms a patina under wet-dry cycles
  - Patina is a stable oxide that eliminates the need for painting
  - If material remains wet due to continual drainage, ponding, or debris accumulation then patina will not form

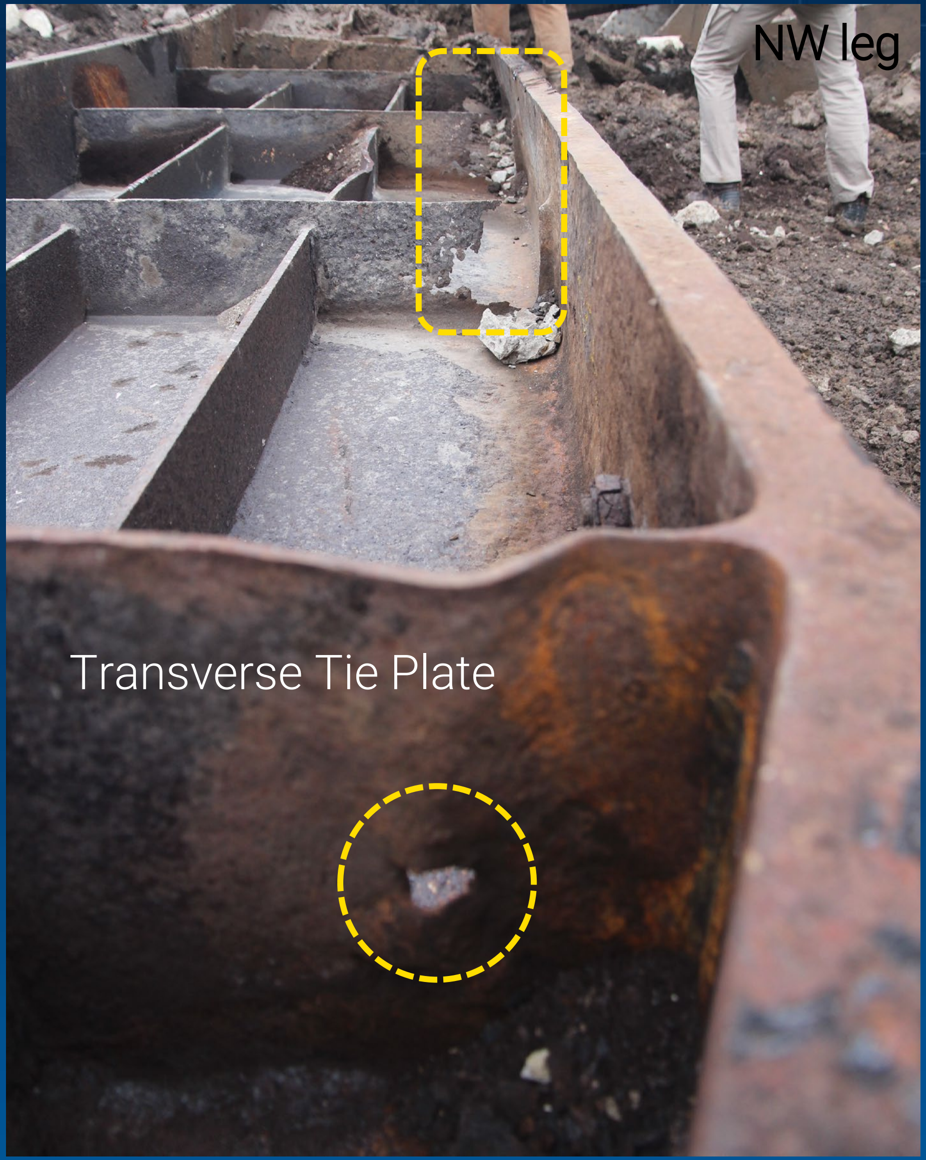
- FHWA Technical Advisory, *Uncoated Weathering Steel in Structures,* October 1989
- National Steel Bridge Alliance and American Institute of Steel Construction, *Uncoated Weathering Steel Reference Guide,* 2022

Corrosion – Leg Shoe

Corrosion product build-up　　Holes　　Transverse tie plate thinning

Corrosion – Leg Stiffeners





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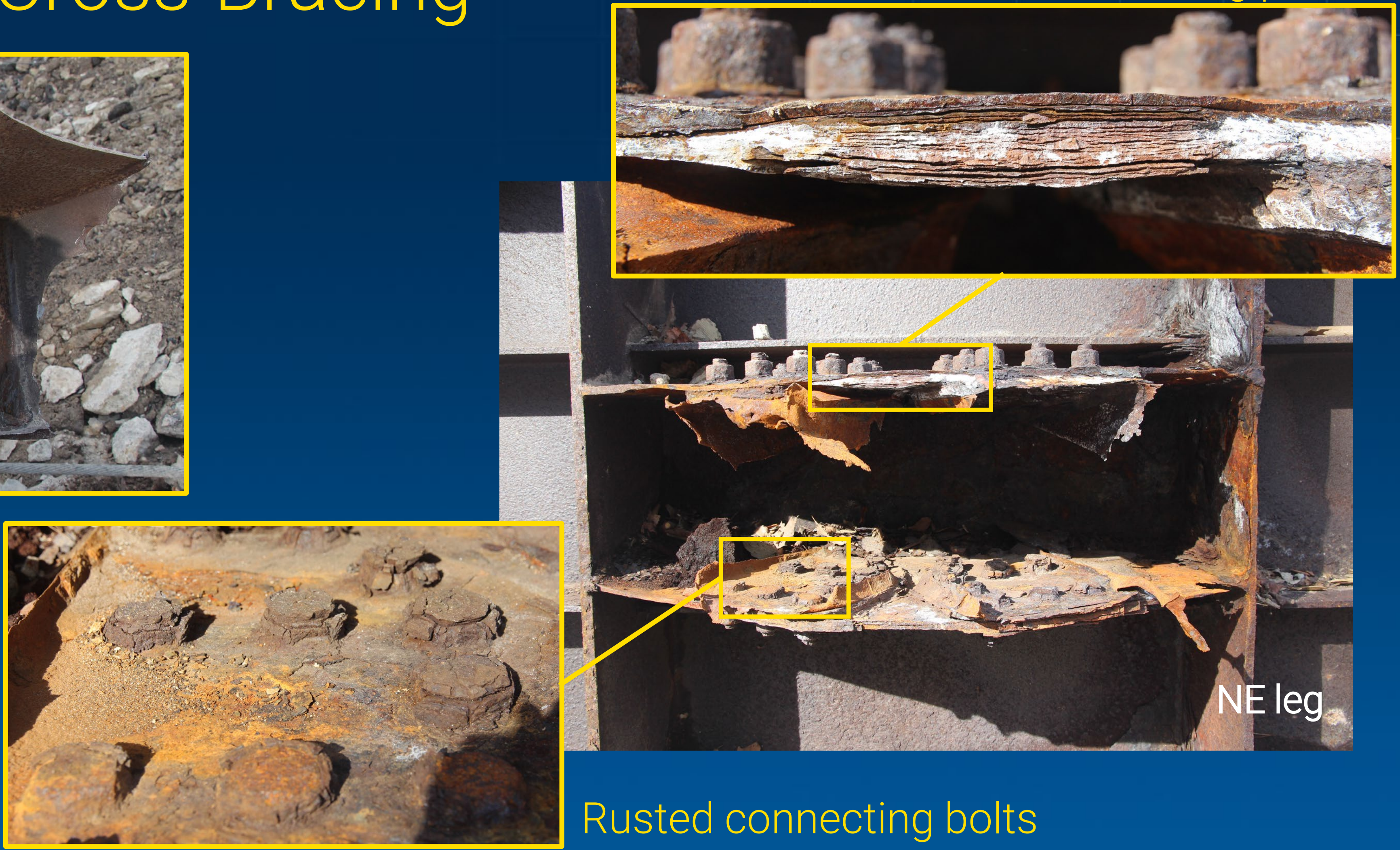
Corrosion – Cross-Bracing

Holes in cross-bracing end

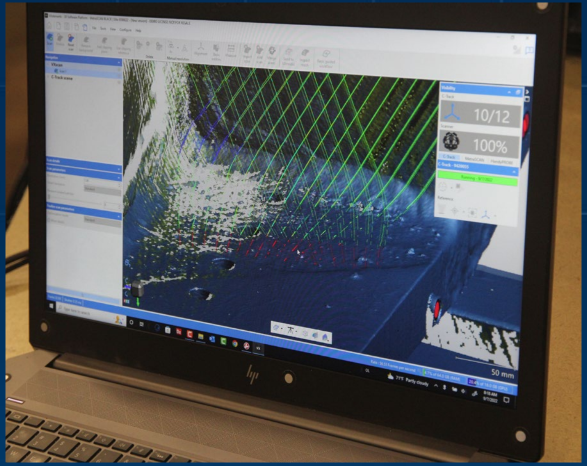
Lamellar corrosion in connecting plates



Rusted connecting bolts

3D Laser Scanning

- Portable optical coordinate measuring machine with 3D laser scanning ability
  - Utilizes probes with line-of-sight positioning
  - Multiple scans merged into one data cloud
  - Cohesive data cloud builds the object in three-dimensional space
- Scanning performed on the pieces collected from the bottom of each leg
  - Resulted in 3D models of each leg piece



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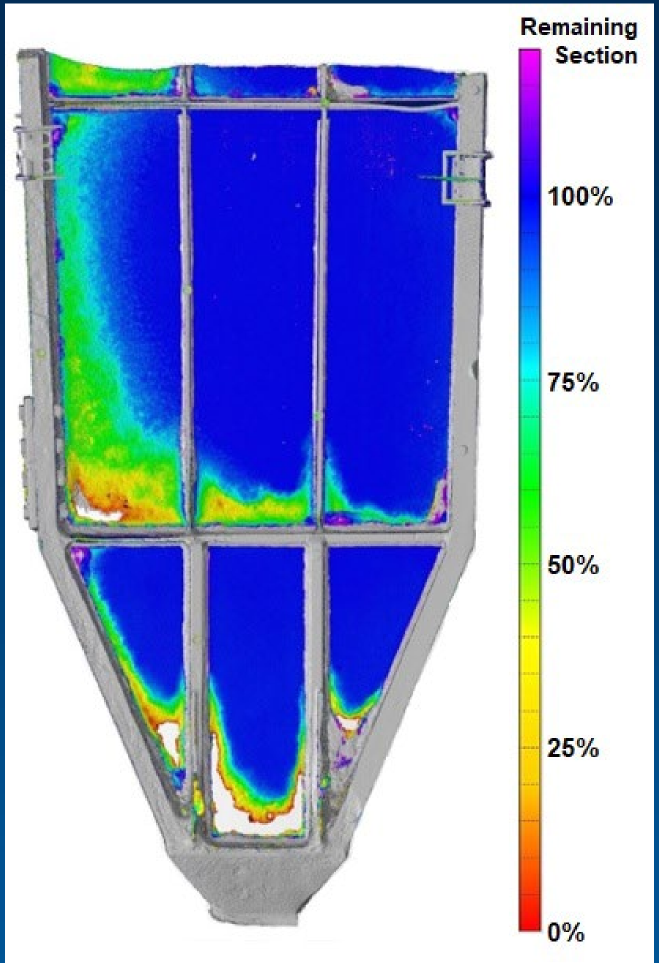
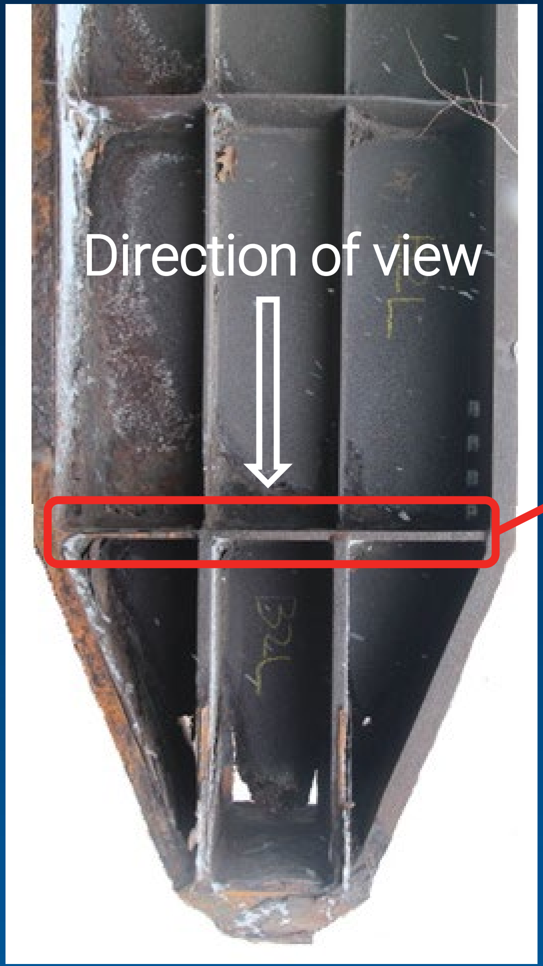
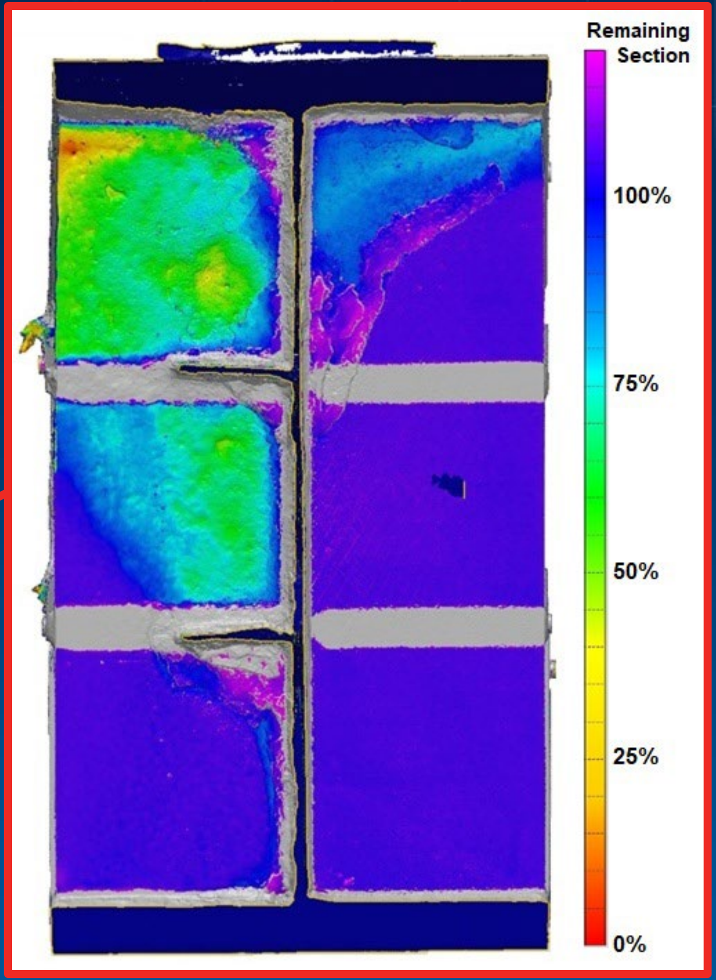
3D Laser Scanning – Northeast Leg







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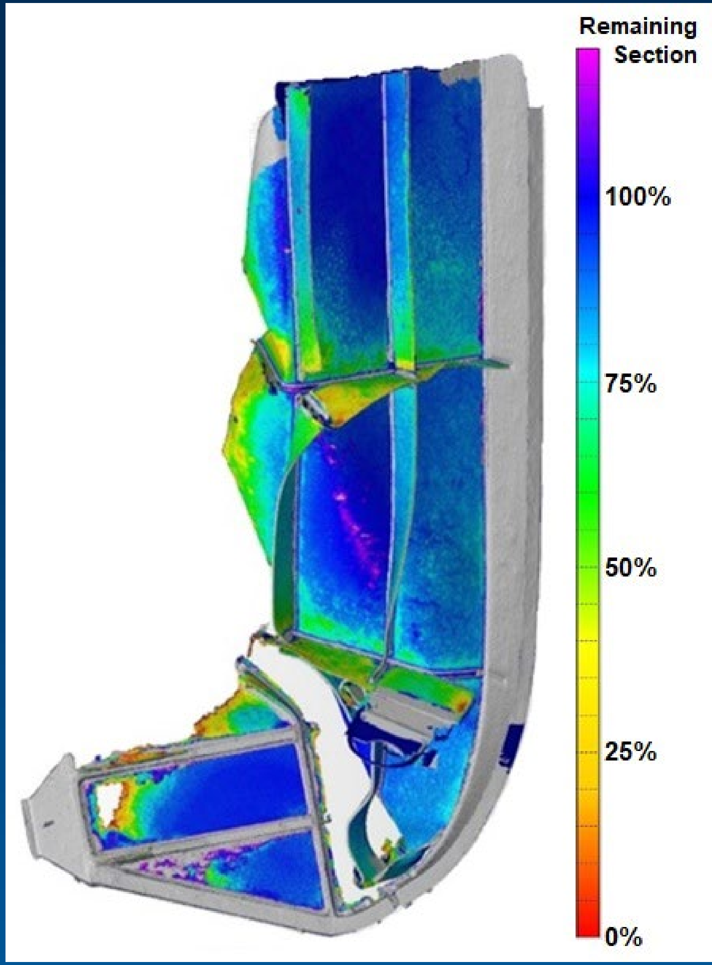
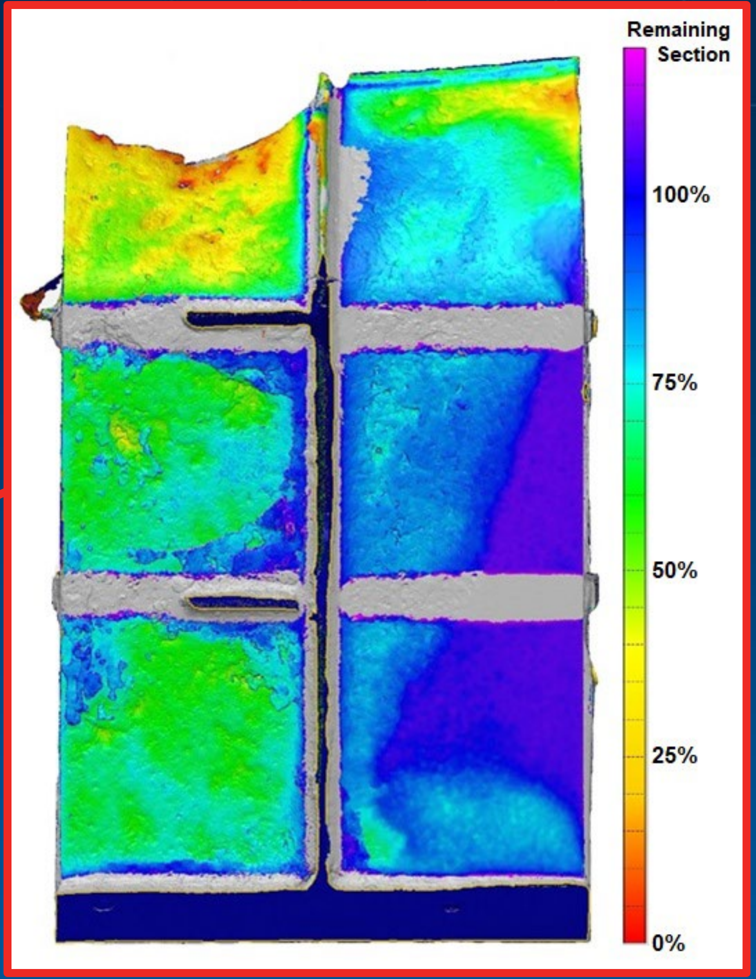
3D Laser Scanning – Southwest Leg





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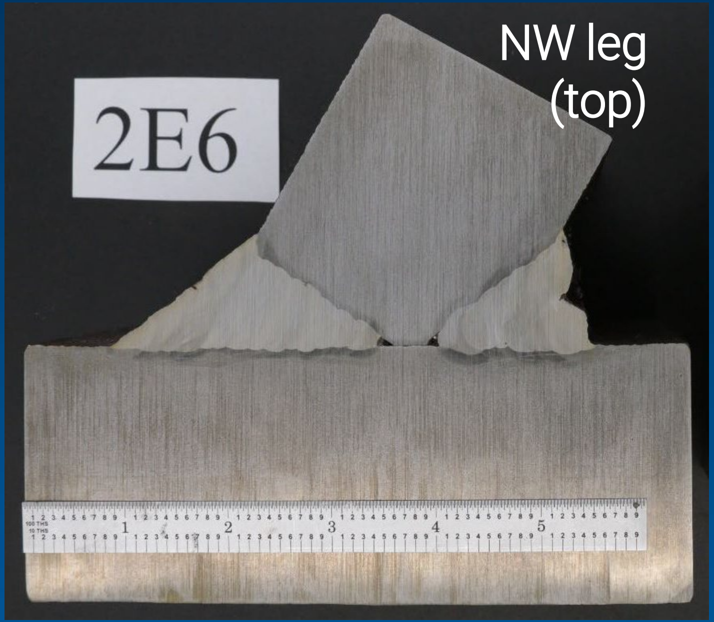
Materials Testing

- ASTM A588 steel plates
- Mill test reports listed tensile strength, impact strength, and chemistry for each plate
  - 26 plates provided by 2 steel mills
- Evaluated plate microstructure
  - Examined integrity of welds
- Testing conducted at FHWA Turner-Fairbank Highway Research Center



Source: FHWA-TFHRC

Source: NTSB

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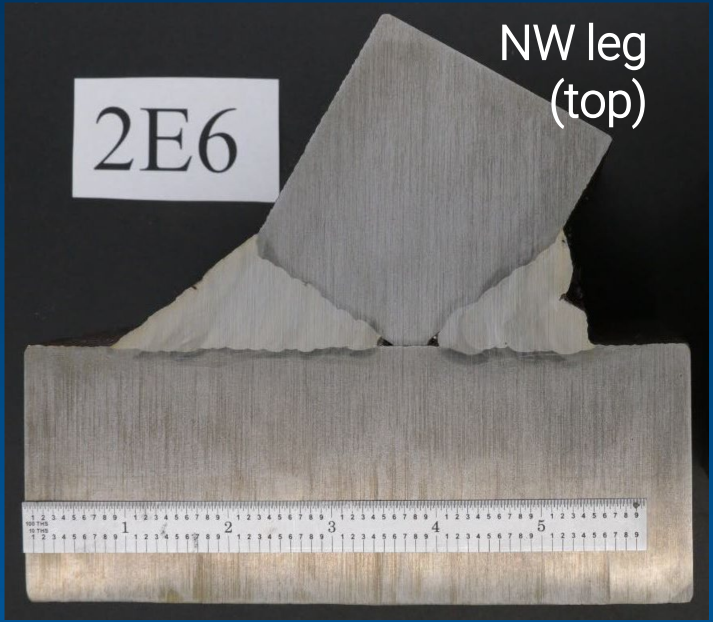
Materials Testing

- Tensile strength
  - Most plates met requirements
  - A few plates located in girders were at most 4% below minimum standards
- Impact strength
  - All plates met requirements
- Chemistry
  - Several plates non-conformant
  - All plates could form patina
- Metallographic examination
  - Welds showed corrosion, lack of fusion



Source: FHWA-TFHRC

Source: NTSB

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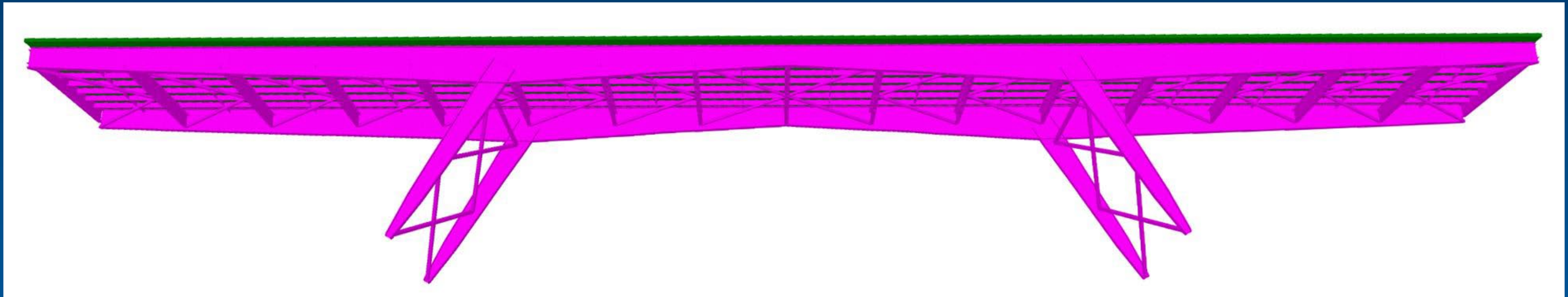
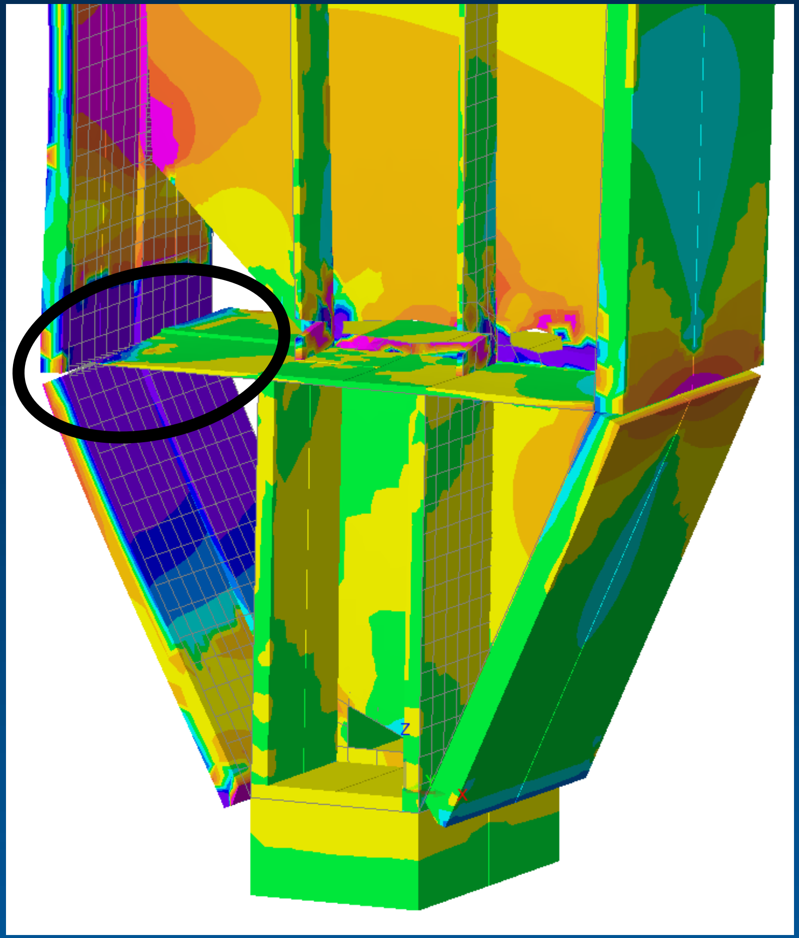
Finite Element (FE) Model

- Global behavior of structure during collapse
  - Use design plans to construct Fern Hollow Bridge
- Local behavior of bottom of legs
  - Incorporate results from 3D laser scanning and materials testing



Source: Modjeski & Masters

FE Model – Cause of Collapse

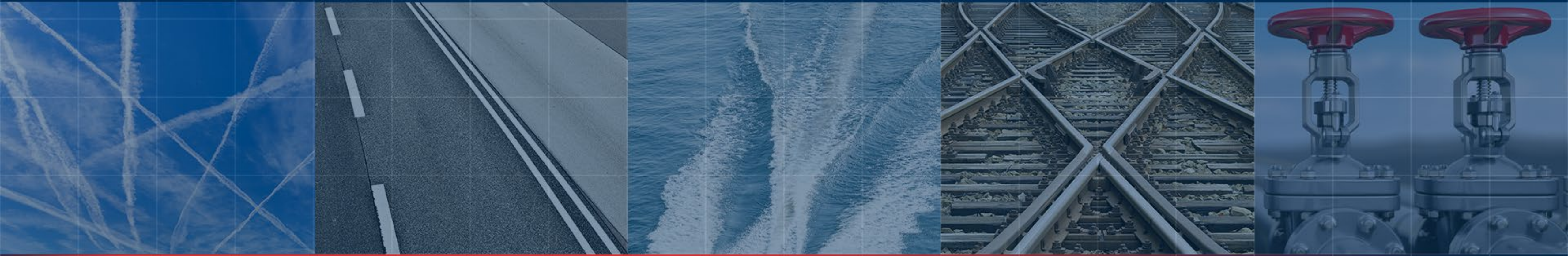


Source: Modjeski & Masters

- Global behavior of structure during collapse
  - As-designed bridge had sufficient capacity to support all loads
- Local behavior of bottom of legs
  - Model of southwest leg shows corrosion present results in decreased capacity
    - When loaded, separation of transverse tie plate at the flange occurs first

What We Found: *Corrosion and Cause of Collapse*

- The southwest leg failed because it had reduced capacity due to extensive corrosion and section loss
  - The collapse initiated at the corroded transverse tie plate
- The following were excluded as factors in the collapse:
  - Use of uncoated weathering steel
  - Materials fabrication
  - Weld quality
  - Bridge design



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Bridge Inspections

Steve Prouty, PE
Senior Structural Engineer

Overview

- Fern Hollow Bridge inspection reports
- Inspection findings and maintenance recommendations
- NTSB Interim Safety Recommendation Report
- Quality of the Fern Hollow Bridge inspections
- Fern Hollow Bridge fracture-critical member inspection plans
- Guidance on fracture-critical member identification

Fern Hollow Bridge Inspection Reports

Bridge Inspections

- Why bridges are inspected
  - To ensure they are safe for the traveling public
  - To prevent structural or functional failures
  - To guide asset management decisions
- Inspection guidance and responsibilities
  - FHWA establishes National Bridge Inspection Standards (NBIS)
  - States are responsible for carrying out NBIS
  - In Pennsylvania, PennDOT has overall responsibility, including for locally owned bridges

Fracture-Critical Members

- A fracture-critical member (FCM)
  - Is made of steel
  - Is fully or partially in tension
  - Failure of the member will cause the bridge to partially or fully collapse
- FCM is synonymous with Nonredundant Steel Tension Member (NSTM)

Fern Hollow Bridge Inspections

- City of Pittsburgh responsible for inspection and maintenance
- Subject to Routine and FCM inspections
- Interim FCM inspections required
  - Reduced load rating in 2014 – 26 tons
  - Poor condition rating
- Conducted by two or more certified bridge safety inspectors

Inspection Date	Inspection Type
September 2005	Routine & FCM
September 2007	Routine & FCM
September 2009	Routine & FCM
September 2011	Routine & FCM
September 2013	Routine & FCM
September 2014	Interim FCM
September 2015	Routine & FCM
September 2016	Interim FCM
September 2017	Routine & FCM
March 2018	Interim FCM
September 2018	Interim FCM
September 2019	Routine & FCM
September 2020	Interim FCM
September 2021	Routine & FCM

Maintenance Priority Codes

Maintenance Priority Code	Short Definition	Action Timeframe
0 CRITICAL	Immediate Response Required	Within 7 Days
1 HIGH PRIORITY	As Soon as Work can be Scheduled	Within 6 Months
2 PRIORITY	Review Work Plan and Re-Prioritize Schedule	Routine Inspection Interval
3 SCHEDULE	Add to Scheduled Work	Add to Schedule
4 PROGRAM	Add to Programmed Work	When Funds are Available
5 ROUTINE	As Per Existing Maintenance Schedule	Within the Next Work Cycle

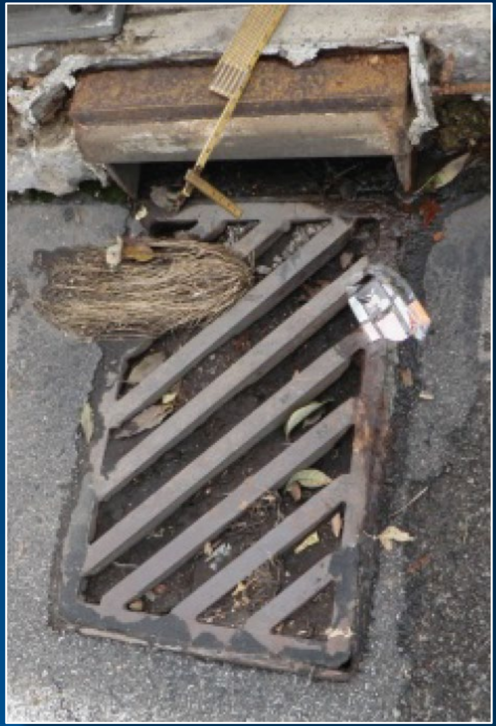
Inspection Findings and Maintenance Recommendations

Clogged Drainage Inlets

2005

Source: 2005 inspection report

2011



Source: 2011 inspection report

2017

Source: 2017 inspection report

2021

Source: 2021 inspection report

Stiffeners on Southwest Leg

2013

Source: 2013 inspection report

2021

Source: 2021 inspection report

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Cross-Bracing

2005 (Southwest Leg)

Source: 2005 inspection report

2021 (Southeast Leg)

Source: 2021 inspection report

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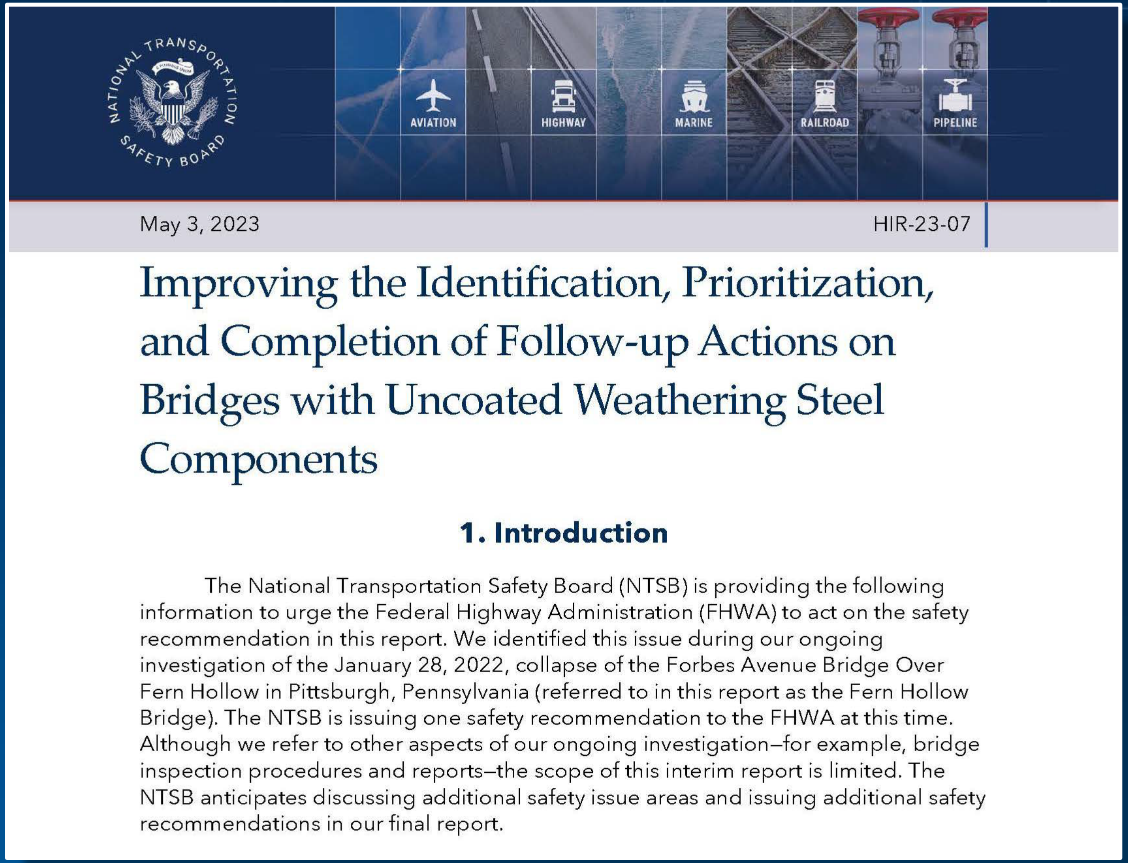
What We Found: *Incomplete Maintenance*

- Significant corrosion and section loss on the southwest leg
- Failure by City of Pittsburgh to act on repeated maintenance and repair recommendations
- Progressive deterioration and structural failure

NTSB Interim Safety Recommendation Report

NTSB Interim Safety Recommendation Report

- Investigation findings led to May 2023 report
- Recommendation H-23-13 to FHWA to develop process to identify, prioritize, and perform incomplete actions for UWS bridges
- FHWA issued a memorandum to state DOTs on July 19, 2023, in response to the NTSB recommendation



May 3, 2023 HIR-23-07

Improving the Identification, Prioritization, and Completion of Follow-up Actions on Bridges with Uncoated Weathering Steel Components

1. Introduction

The National Transportation Safety Board (NTSB) is providing the following information to urge the Federal Highway Administration (FHWA) to act on the safety recommendation in this report. We identified this issue during our ongoing investigation of the January 28, 2022, collapse of the Forbes Avenue Bridge Over Fern Hollow in Pittsburgh, Pennsylvania (referred to in this report as the Fern Hollow Bridge). The NTSB is issuing one safety recommendation to the FHWA at this time. Although we refer to other aspects of our ongoing investigation—for example, bridge inspection procedures and reports—the scope of this interim report is limited. The NTSB anticipates discussing additional safety issue areas and issuing additional safety recommendations in our final report.

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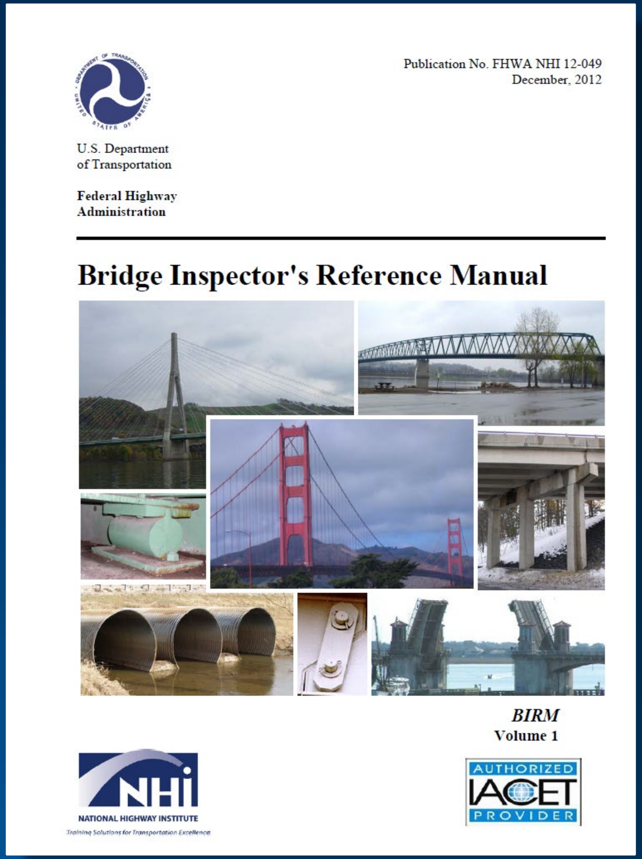
What We Found: *Safety Recommendation H-23-13*

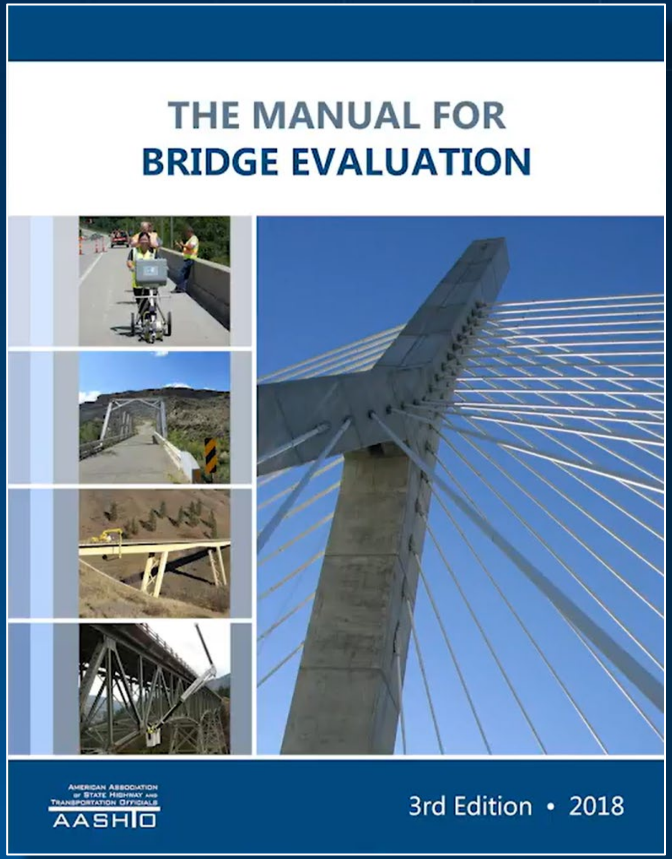
- FHWA’s response meets the intent of NTSB Safety Recommendation H-23-13
- What we propose:
  - Classify Safety Recommendation H-23-13 Closed—Acceptable Action

Quality of the Fern Hollow Bridge Inspections

Bridge Inspection Guidance



Source: FHWA, *Bridge Inspector's Reference Manual (BIRM)*, December 2012 Edition



Source: American Association of State Highway and Transportation Officials, *Manual for Bridge Evaluation (MBE)*, 3rd Edition

Quality of Fern Hollow Bridge Inspections

- Failed to:
  - Clean corrosion before measuring
  - Accurately quantify remaining material
  - Accurately rate the general bridge superstructure condition
  - Recommend a structural review of the bridge legs

Source: 2015 inspection report

What We Found: *Lack of Quality Inspections*

- Inspectors failed to perform the inspections in compliance with the NBIS
- These failures contributed to the bridge's failure to support the loads it was rated for before the collapse

Fern Hollow Bridge Fracture-Critical Member Inspection Plans

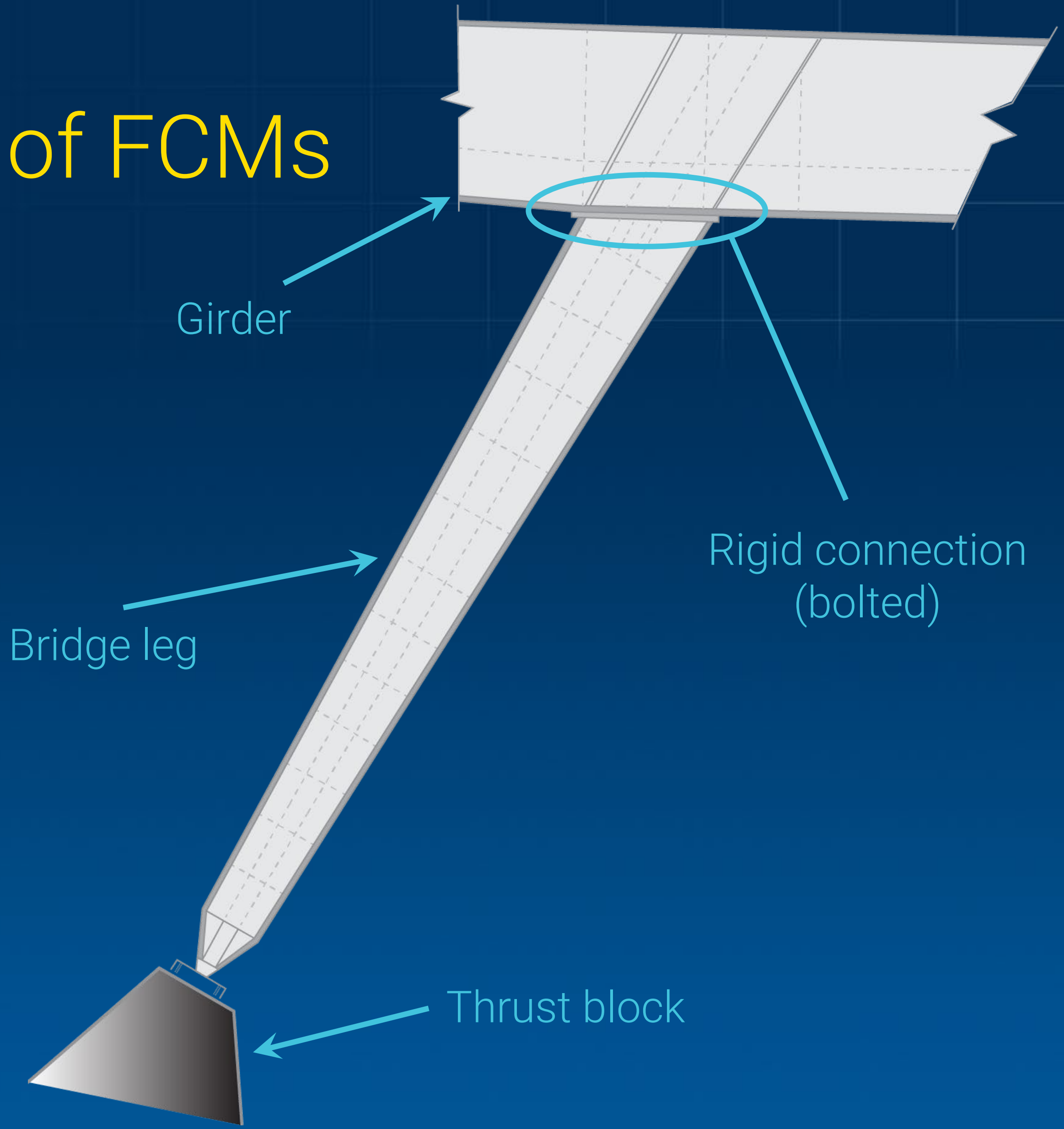
Fracture-Critical Member Inspections

- Required under NBIS for all bridges that contain FCMs
- More rigorous than routine inspections
  - Must identify defects that could lead to failure of critical components

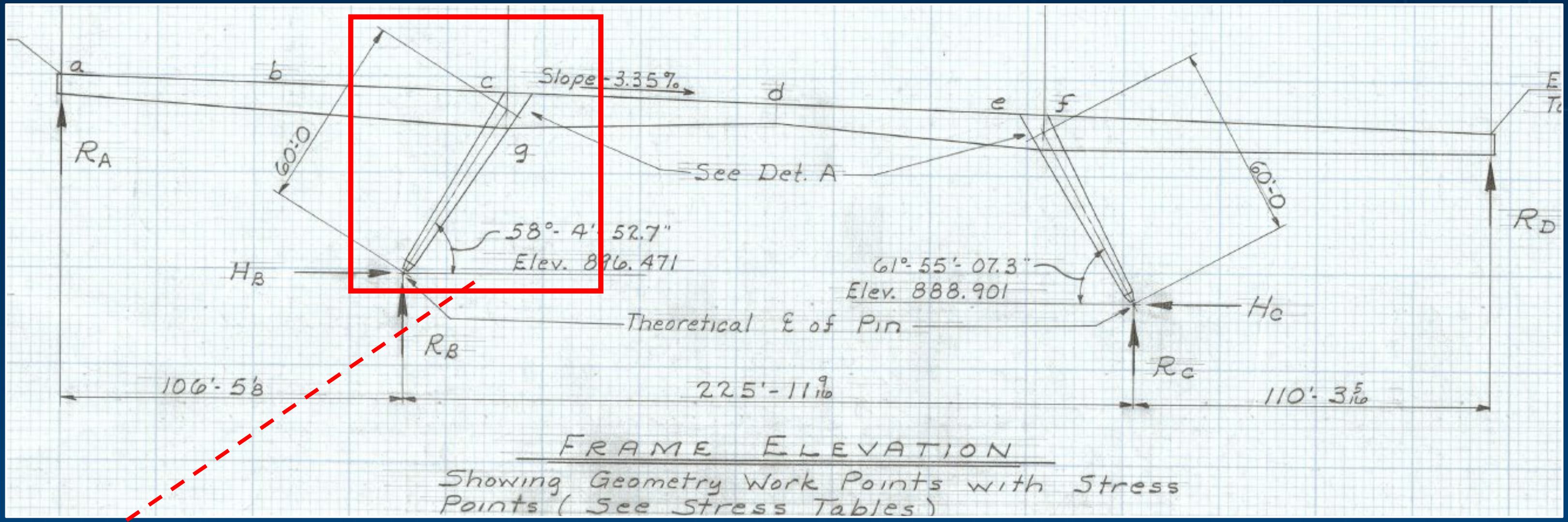
- FCM inspection requirements
  - Written and well documented FCM inspection plan
  - Hands-on (within arm's reach) inspection of all FCMs or member components
  - May include visual inspection as well as other nondestructive evaluation

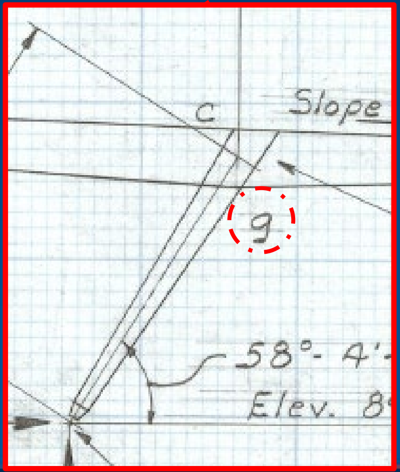
Postcollapse Identification of FCMs

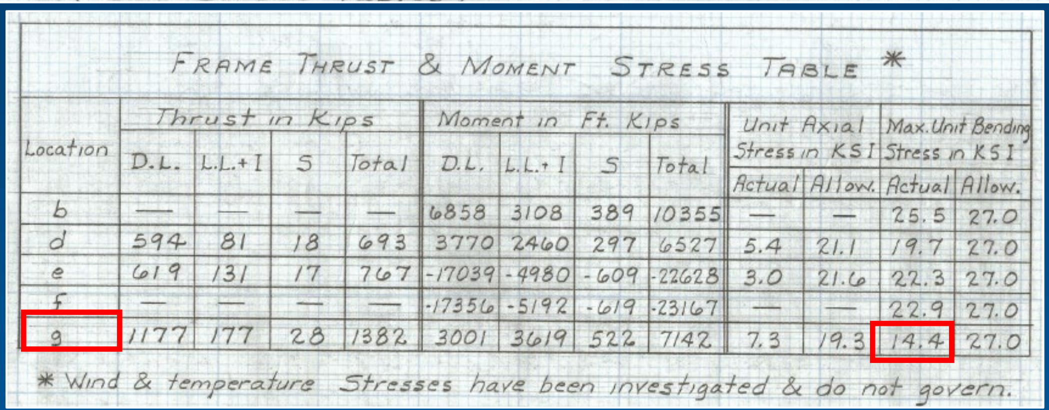
- Rigid connection between girders and bridge legs would have transferred bending moments
- Transferred bending moments (forces) would have added to those originating in the legs due the angled connection



Design Plan Bending Stresses







FRAME THRUST & MOMENT STRESS TABLE *

Location	Thrust in Kips				Moment in Ft. Kips				Unit Axial Stress in KSI		Max. Unit Bending Stress in KSI	
	D.L.	L.L.+I	S	Total	D.L.	L.L.+I	S	Total	Actual	Allow.	Actual	Allow.
b	—	—	—	—	6858	3108	389	10355	—	—	25.5	27.0
d	594	81	18	693	3770	2460	297	6527	5.4	21.1	19.7	27.0
e	619	131	17	767	-17039	-4980	-609	-22628	3.0	21.6	22.3	27.0
f	—	—	—	—	-17356	-5192	-619	-23167	—	—	22.9	27.0
g	1177	177	28	1382	3001	3619	522	7142	7.3	19.3	14.4	27.0

* Wind & temperature Stresses have been investigated & do not govern.

Source: Design Plans for Reconstruction of Forbes Avenue Bridge Over Fern Hollow & Approaches, 1970

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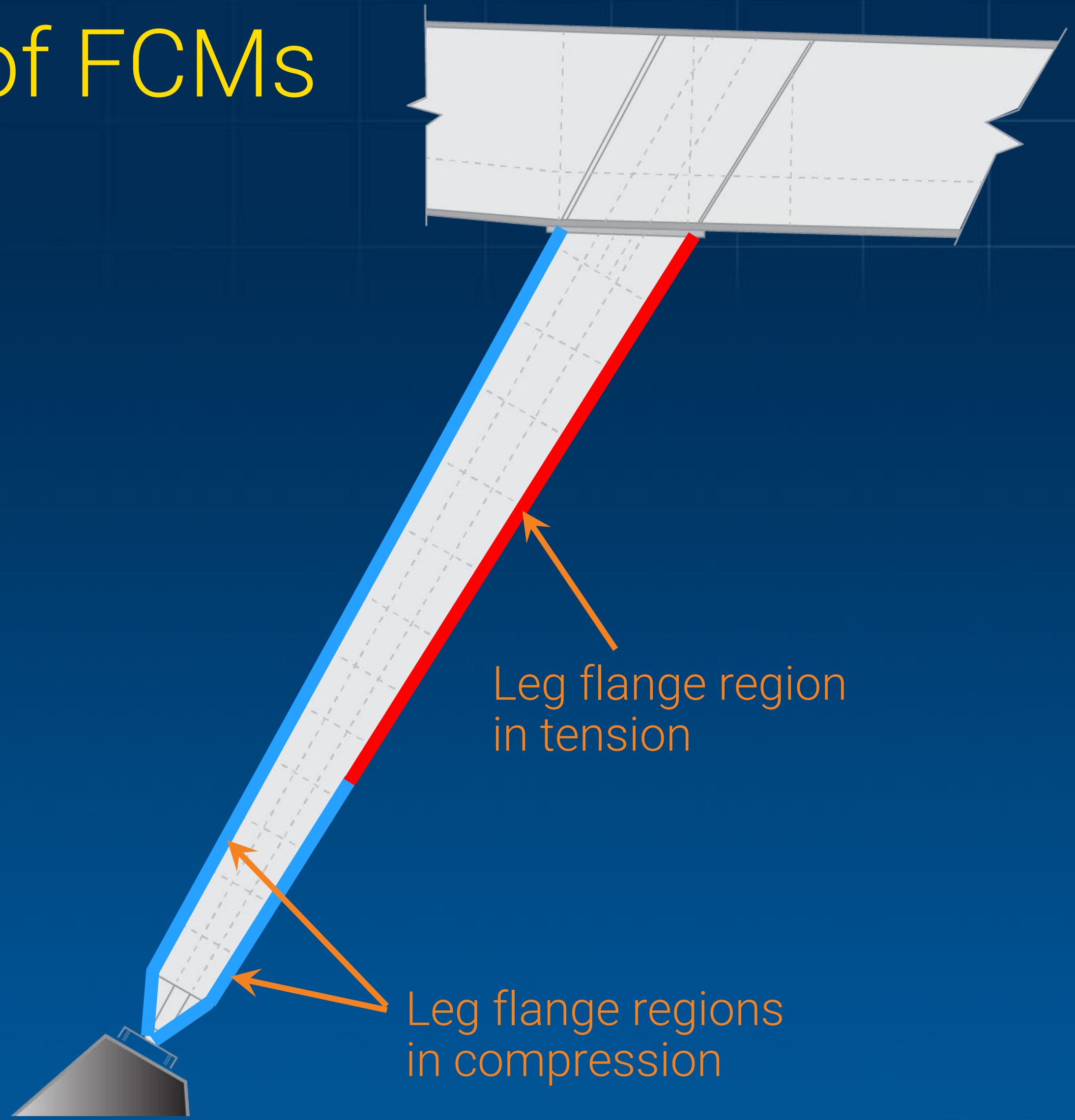
Postcollapse Identification of FCMs



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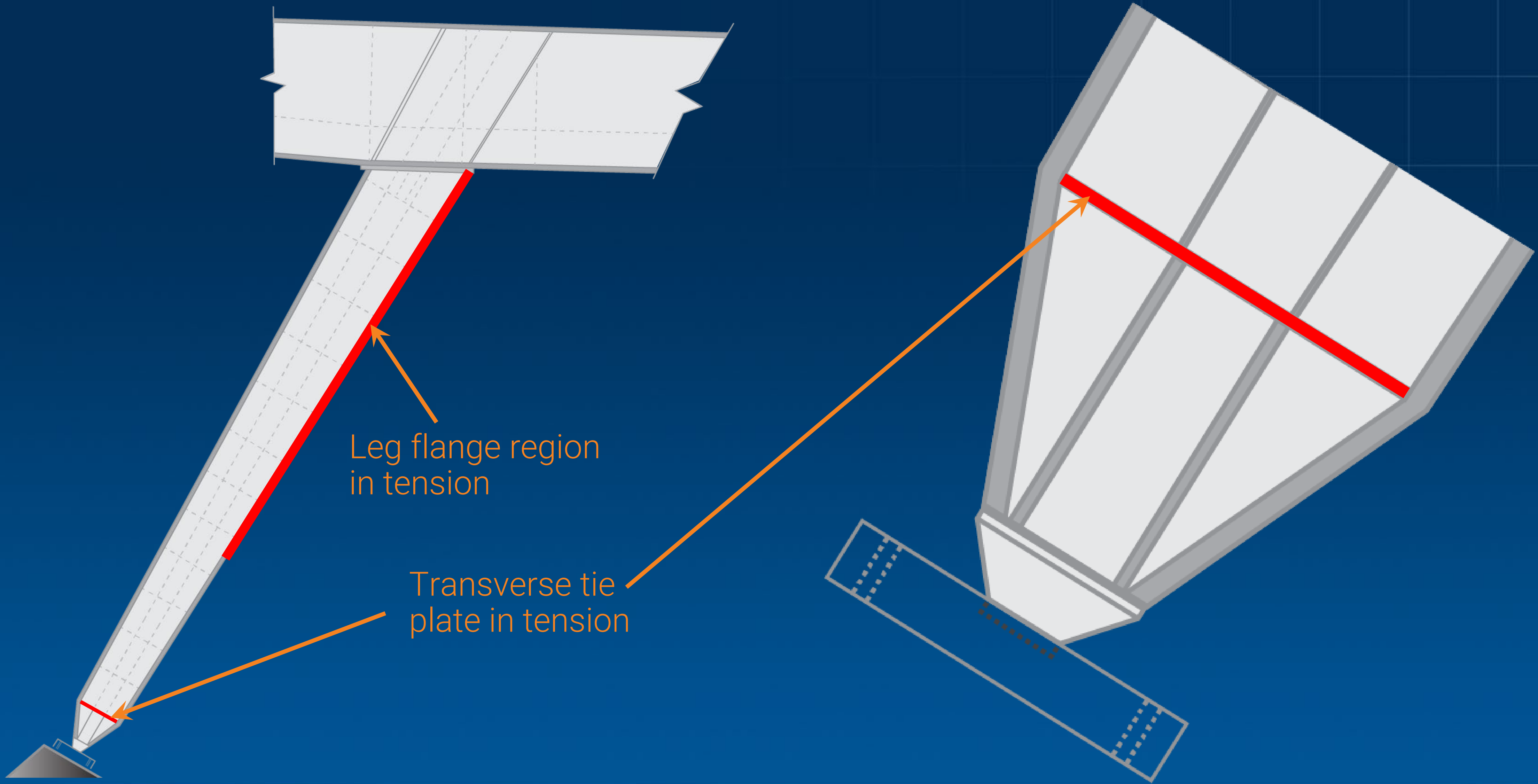
Postcollapse Identification of FCMs



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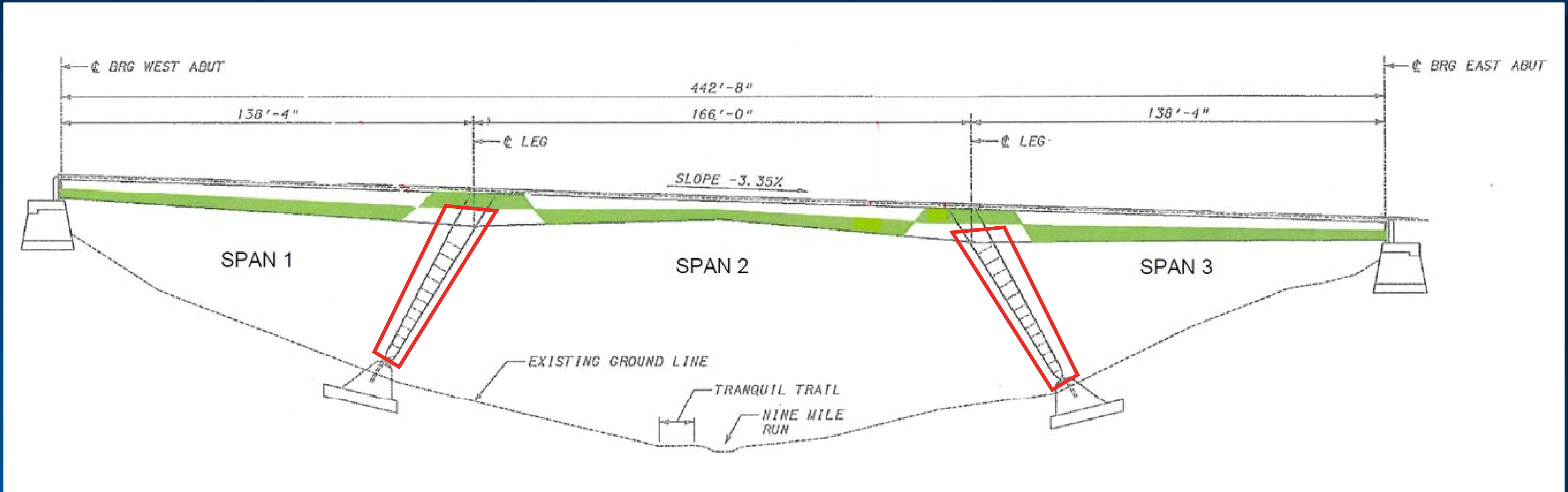
Fern Hollow Bridge Fracture-Critical Member Inspection Plans



Source: Fatigue and Fracture Bridge Inspection Plan for Forbes Avenue Over Fern Hollow and Nine Mile Run, CDM Smith, January 2016

PennDOT Maintenance Recommendation Priority Codes

Maintenance Priority Code	Short Definition	Action Timeframe
0 CRITICAL	Immediate Response Required	Within 7 Days
1 HIGH PRIORITY	As Soon as Work can be Scheduled	Within 6 Months
2 PRIORITY	Review Work Plan and Re-Prioritize Schedule	Routine Inspection Interval
3 SCHEDULE	Add to Scheduled Work	Add to Schedule
4 PROGRAM	Add to Programmed Work	When Funds are Available
5 ROUTINE	As Per Existing Maintenance Schedule	Within the Next Work Cycle

What We Found: *FCM Inspection Plans*

- Bridge legs were not properly identified as fracture-critical
- Bridge legs did not consistently undergo an in-depth FCM inspection
- Maintenance and repair recommendations for the bridge legs were not assigned appropriate priority codes
- Repairing the bridge legs could have prevented the collapse
- The correct identification of FCMs is crucial
- What we propose:
    - One recommendation to the Federal Highway Administration

Guidance on Fracture-Critical Member Identification

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Lack of Guidance for Identifying FCMs in Areas of Global Compression

- Except for the transverse tie plates and adjacent web, the bottom 1/3 of the bridge legs were in compression
- Transverse tie plates were critical to structural stability, yet failure risk went unidentified
- Neither the *BIRM* nor the *MBE* address the identification of bridge components in localized tension zones

Source: 2021inspection report

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What We Found: *FCM Identification Guidance*

- The lack of guidance on localized tension zones may have contributed to the failure to identify the legs as FCMs

- What we propose:
  - One recommendation to the Federal Highway Administration
  - One recommendation to the American Association of State Highway and Transportation Officials

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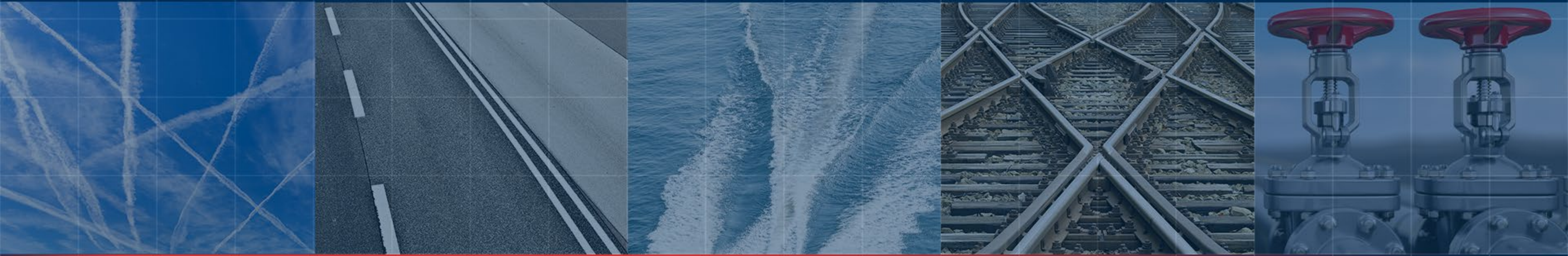

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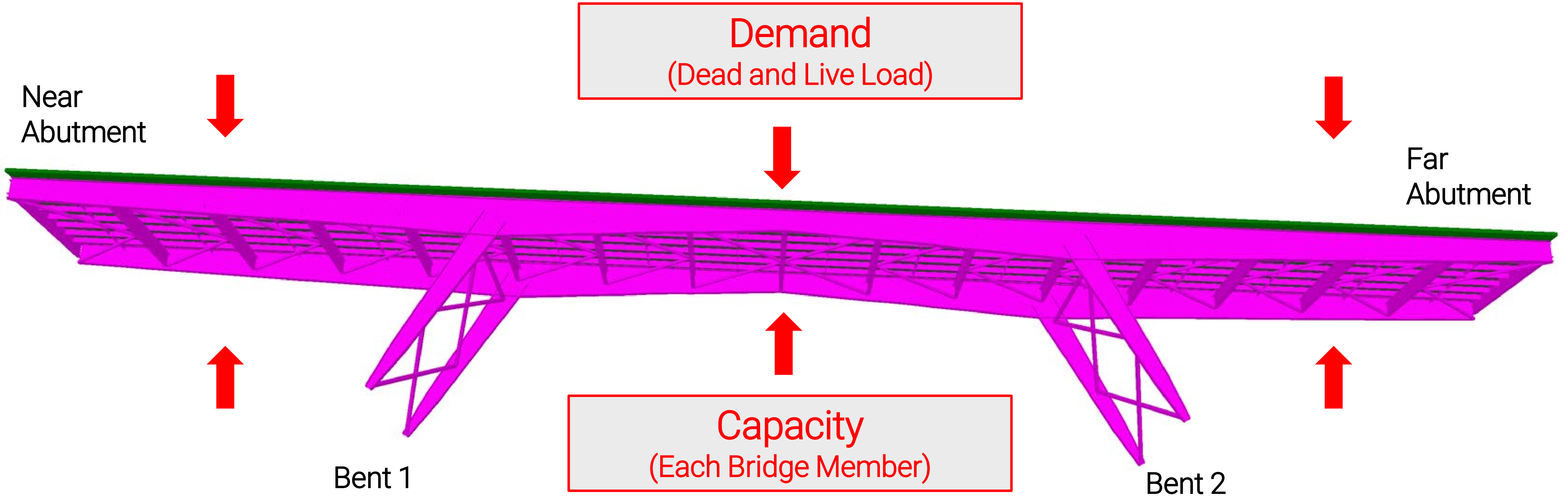
Load Rating Analysis and Bridge Inspection Program Oversight

Dan Walsh, PE
Senior Structural Engineer

Overview

- Several failures allowed the Fern Hollow Bridge to remain open when it should have been closed
  - Failure to perform an adequate bridge load rating
  - Failure to measure an accurate asphalt wearing surface thickness
  - Insufficient oversight by the City of Pittsburgh, PennDOT, and the FHWA regarding bridge inspections

What is a Bridge Load Rating?



Source: Modjeski and Masters, Inc.

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Fern Hollow Bridge Posted Weight Limit

- Posted weight limit of 26 tons
- Load rating analysis conducted in 2014
- In response to 2013 routine inspection report to perform an analysis of the structure's stability
- NTSB investigators found 3 issues with the 2014 load rating analysis

Source: Google street view looking to the west. Imagery date July 2017.

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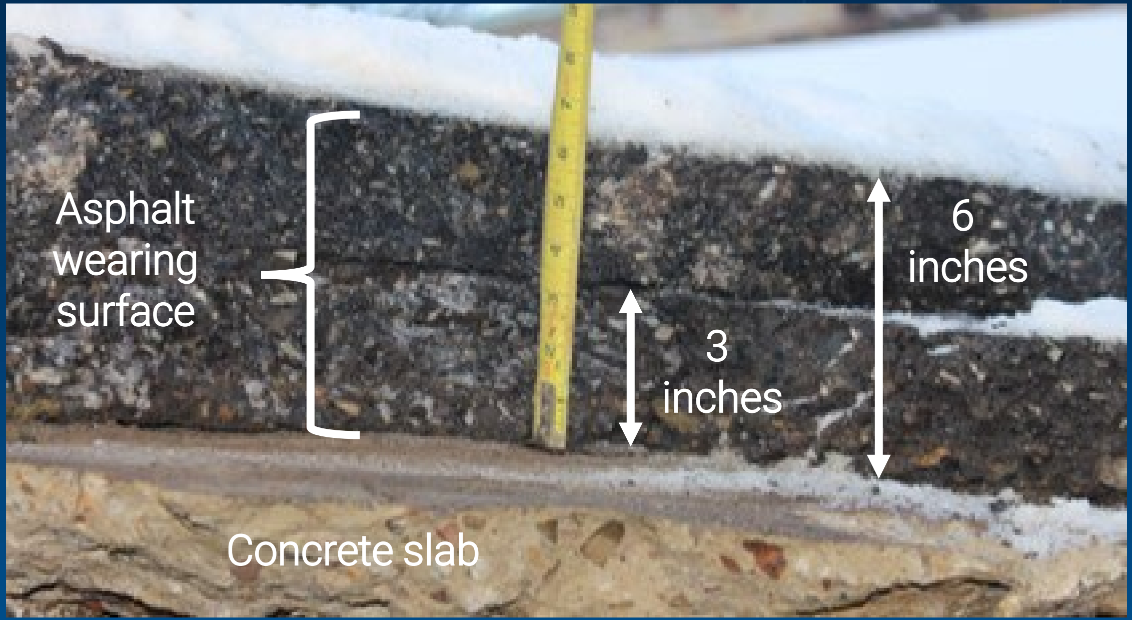
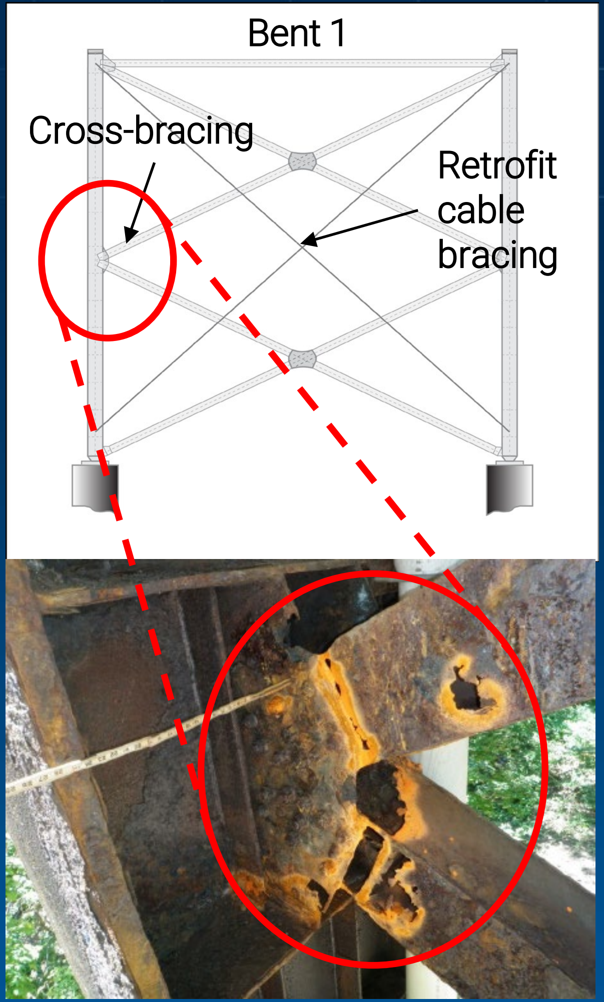
Wearing Surface Thickness

- Thickness of asphalt wearing surface was 3 inches in 2014 load rating
- Postcollapse, the wearing surface thickness was measured to be about 6 inches
- Doubled wearing surface would have resulted in a load posting of less than 26 tons



k-factor for the Bridge Legs

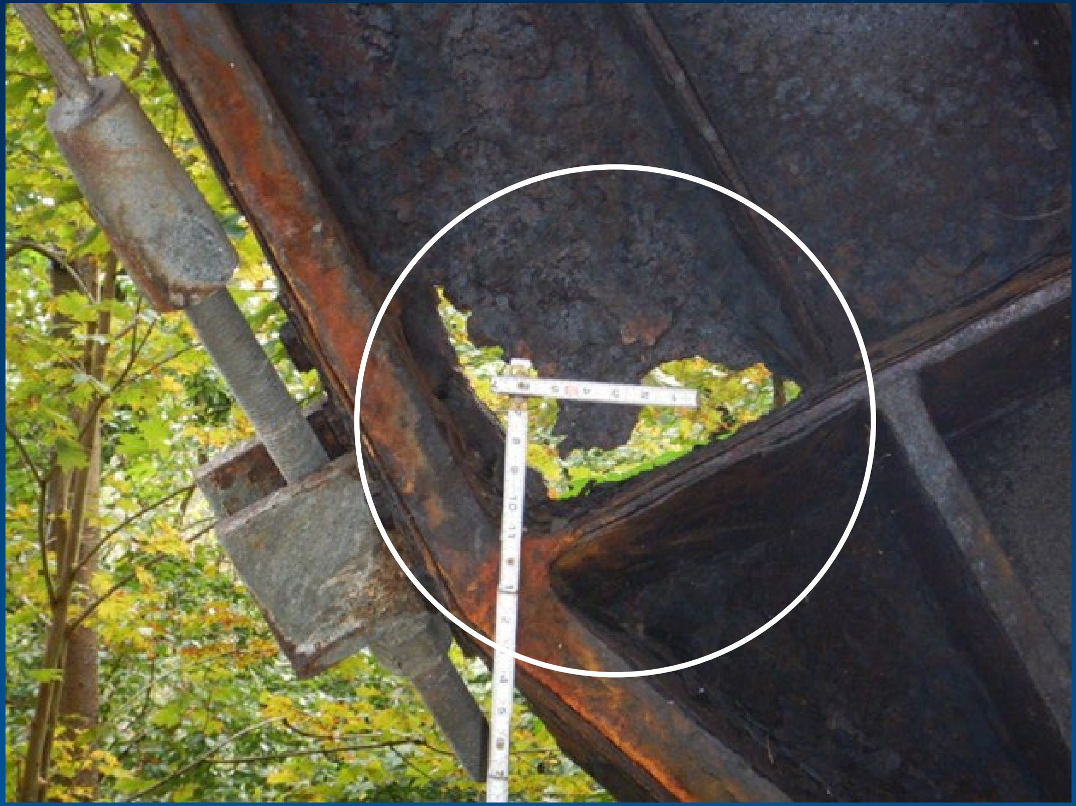
- Load rating assumed an incorrect k-factor
  - When the cross-bracing for the legs was intact
- 2013 routine inspection report indicated the cross-bracing exhibited 100% section loss
- Retrofit cable bracing between the legs was not designed to provide lateral support
- k-factor overestimated each leg's capacity



Source: 2013 inspection report

Section Loss of Leg Web

- Distributed the loss material over the entire length of the leg
- Load rating calculated a new equivalent web thickness for the legs
- Resulted in overestimation of the bridge's capacity



Source: 2021 inspection report

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What We Found: *Load Rating Deficiency*

- The calculations and assumptions used in the 2014 load rating analysis overestimated the Fern Hollow Bridge's capacity
- Had the correct calculations and assumptions been used, the bridge would have been closed

Measuring Accurate Wearing Surfaces

- Affects the estimation of the dead load, which in turn affects the load rating analysis
- Actual asphalt thickness was nearly double the 3 inches specified in the design plan and assumed in the 2014 load rating
- Except for 2017 records, City of Pittsburgh paving records did not document how much asphalt was removed and replaced
- Had the load rating engineer been aware of the thicker asphalt wearing surface
  - In combination with other factors, the bridge's capacity would have been lowered

What We Found: *City of Pittsburgh Poor Record Keeping*

- Quality of the City's paving record was so poor, determinations could not be made about
  - Whether the actual asphalt wearing surface exceeded what was assumed in the design of the bridge
  - How long the thicker wearing surface had been in place
- What we propose:
  - One recommendation to the City of Pittsburgh

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Techniques to Determine Asphalt Wearing Thicknesses

- Most common technique is collecting core samples
- Coring is the process of removing cylindrical samples of material, which is destructive
  - Allowing water to enter the deck
  - Damaging the asphalt wearing surface
- Other common methods
  - Measuring curb height or driving a nail
  - These methods also have drawbacks

Source: Gilson Company, Inc.

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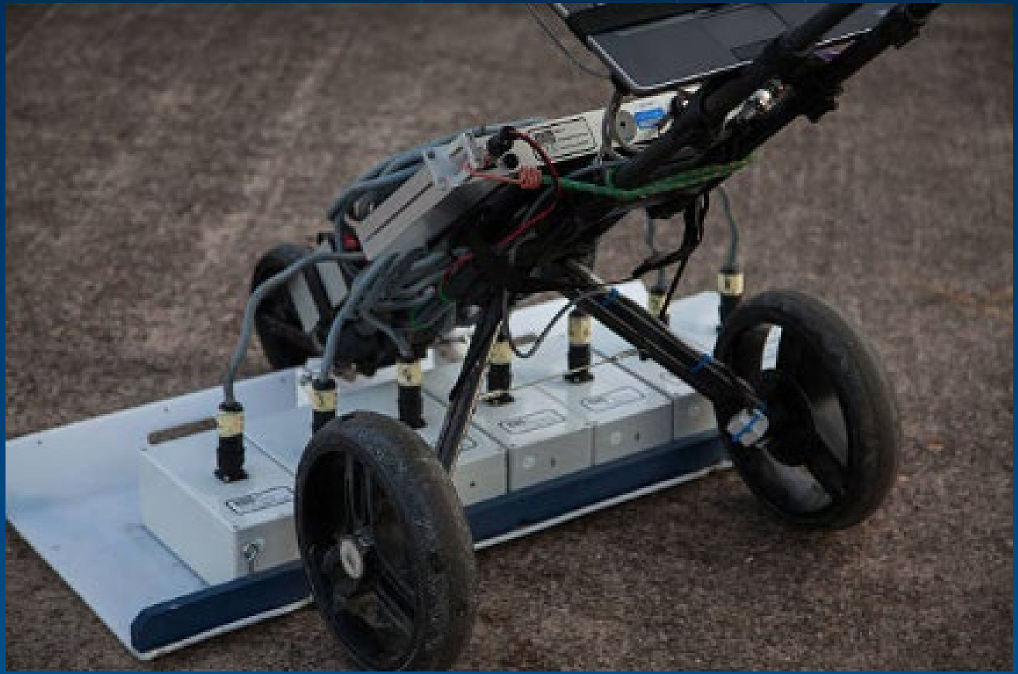
Non-Destructive Method for Assessing Bridge Decks

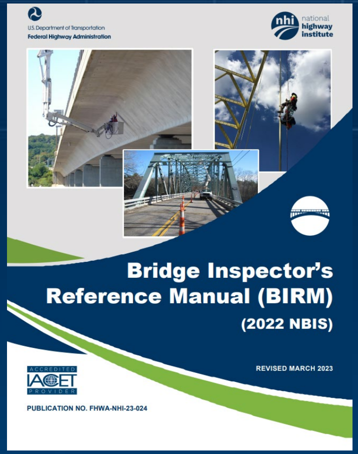
- Ground-penetrating radar (GPR) has been shown to be an effective method
- Some states are already investing in GPR
- Guidance is needed on
  - Approaches to integrating GPR into common practice
  - Promoting greater use of the technology



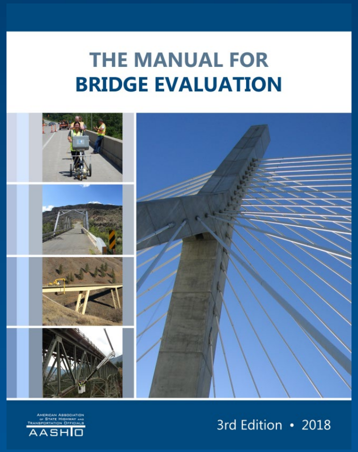
Source: Getty Images

What We Found: *Verify Thickness of Wearing Surface*

- Guidance is needed on the use of non-destructive techniques to verify the actual thickness of the bridge wearing surface
- What we propose:
  - One recommendation to the Federal Highway Administration
  - One recommendation to the American Association of State Highway and Transportation Officials



Source: FHWA



Source: AASHTO

City of Pittsburgh Inspection Failures

- City was responsible for inspecting and maintaining the Fern Hollow Bridge
- Similar maintenance and repair recommendations were made in the inspection reports for more than 15 years leading up to the collapse
  - City failed to act on them
- City records documenting work performed on the bridge was limited and provided little information
- City of Pittsburgh Department of Mobility and Infrastructure postcollapse changes
  - Adding additional personnel and updating load rating analyses

NTSB

What We Found: *Insufficient Oversight by City of Pittsburgh*

- Postcollapse actions completed by the City of Pittsburgh in response to the collapse of the Fern Hollow Bridge have the potential to address the deficiencies found in this investigation
- What we propose:
  - One recommendation to the City of Pittsburgh
  - One recommendation to the Pennsylvania Department of Transportation

PennDOT Noncompliance of Inspections with NBIS

- PennDOT responsible for ensuring bridges are inspected in compliance with the National Bridge Inspection Standards (NBIS)
  - Fern Hollow Bridge inspections were not performed in compliance with NBIS
- Maintenance and repair recommendations with Priority Codes 2 through 5 were not completed
- Between 2005 and 2021, many maintenance and repair items were left unperformed
  - Reinforcing the stiffeners and repairing the rusted holes on all four legs - Priority Code 2
  - Cleaning debris from the superstructure - Priority Code 5

Postcollapse Actions by PennDOT

- Updated November 2022 Technical Bulletin to ensure
  - Priority 2 maintenance needs are correctly classified
  - Drainage systems are operating properly
- Taken steps to improve the inspection process and identify bridges in need of maintenance
- Action should be taken on Priority 2 through 5 codes in a timely manner

pennsylvania
DEPARTMENT OF TRANSPORTATION

Technical Bulletin

Bridge Safety Inspection and Bridge Maintenance Programs

November 14, 2022

Source: PennDOT

What We Found: *Insufficient Oversight by PennDOT*

- Postcollapse actions completed by PennDOT have the potential to identify at-risk bridges
- It is also necessary to ensure that maintenance and repair recommendations are completed in a timely manner
- PennDOT failed to provide sufficient oversight to the City of Pittsburgh
- What we propose:
  - One recommendation to the Pennsylvania Department of Transportation

FHWA Monitors States' Compliance with the NBIS

- Evaluates 23 metrics that correspond to the NBIS
- Assigns a compliance level
  - Compliant, Substantially Compliant, Noncompliant, and Conditionally Compliant
- Selects bridges based on a random sample using a sampling tool
  - Sample of bridges is statistically representative of the overall population of bridges
  - FHWA uses a data-driven system to thoroughly investigate issues identified through these samples

NTSB

FHWA Targeted Data-Driven Reviews

- More than 615,000 bridges in the National Bridge Inventory
  - 23,257 bridges are listed in Pennsylvania
- Targeted reviews are an efficient way for FHWA to investigate bridge safety issues such as those identified in the Fern Hollow Bridge investigation
  - Evaluating the need to conduct new load ratings of bridges with advanced deterioration
  - Evaluating whether the assumptions and methods used in the load rating calculations are correct

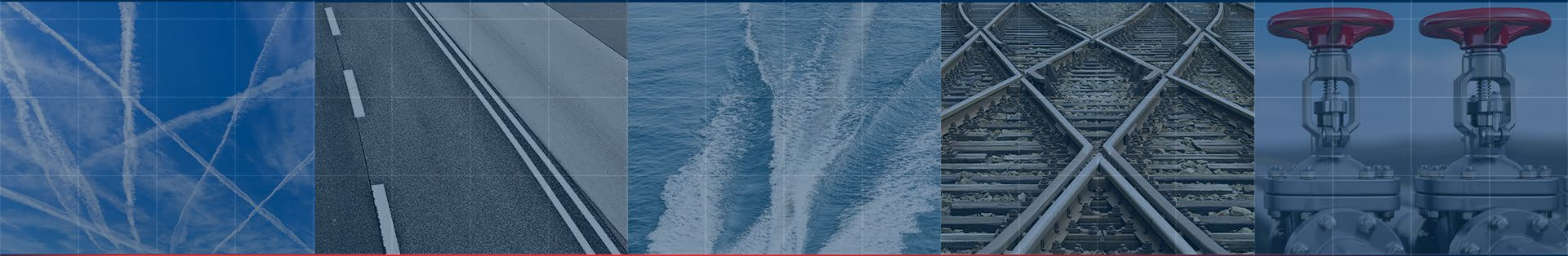
What We Found: *Insufficient Oversight by FHWA*

- Data-driven reviews of targeted bridge populations to investigate specific bridge safety issues will help improve FHWA's oversight process
- Once a problem is identified through the targeted review
  - FHWA can expand its review to address similar bridges to ensure the safety of those bridges for the traveling public
- What we propose:
  - One recommendation to the Federal Highway Administration

NTSB

What We Found: *Sharing of Lessons Learned*

- Consequences of failures to complete inspections in accordance with standards
  - Failure to correctly identify FCMs
  - Failure to correctly perform a load rating analysis
  - Failure to respond to inspection findings and recommendations in a timely manner
- What we propose:
  - One recommendation to the Federal Highway Administration



NATIONAL TRANSPORTATION SAFETY BOARD

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Draft Findings, Probable Cause, and Recommendations

Brian Curtis

Findings

1. None of the following were factors in the collapse: (1) the use of uncoated weathering steel, (2) the design of the bridge, (3) the fabrication materials, (4) the deterioration of the welds, or (5) the qualifications of the 2005–2021 bridge inspection team leaders.
2. The emergency response was timely and adequate.
3. The Fern Hollow Bridge collapsed due to the extensive corrosion and section loss of its fracture-critical members, specifically the transverse tie plate, resulting in the failure of the southwest leg (B1R), which no longer had the structural capacity to carry the bridge's loads at the time of the collapse.

Findings

4. The significant corrosion and section loss on the southwest leg (B1R) resulted from the failure of the City of Pittsburgh to act on the repeated maintenance and repair recommendations documented in inspection reports from 2005 to 2021, leading to progressive deterioration and structural failure.

Findings

5. In response to National Transportation Safety Board Safety Recommendation H-23-13, the Federal Highway Administration developed a risk-based, data-driven process and encouraged its use by state departments of transportation, as well as federal agencies and tribal governments that own and operate bridges, to help them identify, prioritize, and perform follow-up actions documented in inspections of bridges with uncoated weathering steel components.

Findings

6. Multiple inspectors of the Fern Hollow Bridge, contracted by the Pennsylvania Department of Transportation on behalf of the City of Pittsburgh over a period of more than 15 years, failed to (1) clean corrosion before measuring, (2) accurately quantify remaining material, (3) accurately rate the general bridge superstructure condition, and (4) recommend a structural review of the bridge legs; and these failures contributed to the bridge's inability to support the loads it was rated for before the collapse.

Findings

7. In the Fracture-Critical Identification Framing Plans, the Fatigue and Fracture Bridge Inspection Plan, and the handwritten notes contained in the earlier Fern Hollow Bridge inspection reports, Pennsylvania Department of Transportation contractors did not properly identify the bridge legs, including the transverse tie plates, as fracture-critical members (nonredundant steel tension members), and as a result, the legs did not consistently undergo a more in-depth, hands-on fracture-critical member inspection as required by 23 *Code of Federal Regulations* 650 Subpart C.

Findings

8. Had the bridge legs, including the transverse tie plates, been properly identified as fracture-critical members, the inspection recommendations related to repairing and reinforcing section loss and holes in the legs would likely have been assigned a priority code of 0 and prompted action within 7 days.
9. If the City of Pittsburgh had taken appropriate action to repair or reinforce the section loss on the fracture-critical bridge leg components, the collapse of the Fern Hollow Bridge could have been prevented.

Findings

10. The correct identification of fracture-critical members is crucial to ensuring that these members are properly maintained so that they do not fail and result in a partial or full bridge collapse.
11. Bridge inspectors lack adequate guidance from the Federal Highway Administration *Bridge Inspector's Reference Manual* and the American Association of State Highway and Transportation Officials *Manual for Bridge Evaluation* on the proper identification of localized tension zones and tension components to correctly identify fracture-critical members in preparation for and during bridge inspections.

Findings

12. The calculations and assumptions used in the 2014 load rating analysis overestimated the Fern Hollow Bridge's capacity, and if these calculations and assumptions had (1) correctly accounted for the amount of wearing surface on the bridge, (2) used the correct *k*-factor to estimate axial load capacity, and (3) correctly accounted for the localized effects of section loss, the result would have required the closure of the bridge.

Findings

13. The quality of the City of Pittsburgh's paving records was so poor that determinations could not be made about whether the actual asphalt wearing surface exceeded what was assumed in the design of the bridge or about how long the wearing surface had exceeded the as-designed thickness, which contributed to an incorrect load rating analysis.
14. The thickness of a bridge's wearing surface is an important component for calculating load ratings, and non-destructive techniques can provide a means of verifying the actual thickness of the wearing surface without introducing damage to the bridge.

Findings

15. The postcollapse actions completed by the City of Pittsburgh in response to its failure to maintain the Fern Hollow Bridge, which resulted in the bridge's collapse—increased staff in the Bridges and Structures Division, a streamlined funding process for bridge maintenance and repairs, review of load ratings, and approved funding for bridge rehabilitation projects—have the potential to address the deficiencies found in this investigation, including insufficient oversight of needed bridge maintenance and repair activities.

Findings

16. The Pennsylvania Department of Transportation’s insufficient oversight of the City of Pittsburgh’s bridge inspection program contributed to the bridge’s continued deteriorated condition that led to the collapse.

Findings

17. The postcollapse actions completed by the Pennsylvania Department of Transportation—conducting field examinations of fracture-critical K-frame bridges, conducting file reviews of other K-frame bridges and bridges with steel-pier bents, and publishing a Technical Bulletin updating Pennsylvania's Bridge Safety Inspection Program and its Bridge Maintenance Program—have the potential to identify at-risk bridges throughout the state, but it is also necessary to provide proper oversight, including ensuring that maintenance and repair recommendations are appropriately coded, monitored, and completed in a timely manner.

Findings

18. The Federal Highway Administration should use data-driven reviews of targeted bridge populations to investigate specific bridge safety issues such as the validity of load ratings of bridges with advanced deterioration.
19. The Fern Hollow Bridge collapse demonstrates the consequences of failure to complete inspections in accordance with standards, failure to correctly identify fracture-critical members, failure to correctly perform a load rating analysis, and failure of the bridge owner to respond to inspection findings and complete maintenance recommendations in a timely manner.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the collapse of the Fern Hollow Bridge in Pittsburgh, Pennsylvania, was the failure of the transverse tie plate on the southwest leg of the bridge, a fracture-critical member (nonredundant steel tension member), due to corrosion and section loss resulting from the City of Pittsburgh's failure to act on repeated maintenance and repair recommendations from inspection reports. Contributing to the collapse were the poor quality of inspections, the incomplete identification of the bridge's fracture-critical members (nonredundant steel tension members), and the incorrect load rating calculations for the bridge. Also contributing to the collapse was insufficient oversight by the Pennsylvania Department of Transportation of the City of Pittsburgh's bridge inspection program.

Recommendations

To the Federal Highway Administration:

1. Require state departments of transportation, as well as federal agencies and tribal communities that own and operate bridges, to conduct a one-time review of the existing fracture-critical member (nonredundant steel tension member) inspection plans for bridges with nonredundant steel frame leg designs in their inventory, and update these plans as necessary to ensure that all fracture-critical members, especially those in the legs, have been properly identified and accounted for in the fracture-critical member inspection plans and inspections.

Recommendations

To the Federal Highway Administration:

2. Update your *Bridge Inspector's Reference Manual* to include guidance that addresses the identification of localized tension zones and tension components in nonredundant steel members that are generally considered to be fully or partially in compression.
3. Update your *Bridge Inspector's Reference Manual* and bridge inspection training courses to include reference material on the selection, frequency of use, and application of non-destructive inspection methods for assessing the wearing surface thickness on bridge decks.

Recommendations

To the Federal Highway Administration:

4. Establish a process for conducting targeted reviews of the safety issues identified in this investigation, to include at a minimum (1) an evaluation of bridge owners' determinations of the need to conduct new load ratings of bridges with advancing deterioration, and (2) an evaluation of inspection reports on bridges with advanced deterioration to determine if the assumptions and methods used in the load rating calculations are correct; and incorporate the results of these reviews into the *National Bridge Inspection Program Compliance Review Manual* as necessary.

Recommendations

To the Federal Highway Administration:

5. Incorporate the findings of the Fern Hollow Bridge collapse investigation into your bridge inspection training courses and use the Fern Hollow Bridge as a case study to emphasize the need to complete maintenance and repair recommendations from inspection reports, follow guidance to ensure that bridge inspections are properly performed, correctly identify fracture-critical members, and correctly calculate load rating analyses.

Recommendations

To the Pennsylvania Department of Transportation:

6. Work with the City of Pittsburgh to evaluate and publish a report documenting the effectiveness of the changes made by the City of Pittsburgh to ensure that bridges are safe for the traveling public. Evaluated changes should include completing necessary bridge maintenance and repair recommendations and confirming that bridges have correct load ratings that account for deterioration.
7. Develop and implement a plan to publish yearly aggregate data on bridge maintenance and repair recommendations to monitor completion of these recommendations.

Recommendations

To the City of Pittsburgh:

8. Establish a system to ensure that you maintain paving records indicating how much asphalt wearing surface is removed and how much is subsequently placed during every bridge resurfacing operation.
9. In collaboration with the Pennsylvania Department of Transportation, evaluate the effectiveness of the changes made by the City of Pittsburgh to ensure that bridges are safe for the traveling public. Evaluated changes should include completing necessary bridge maintenance and repair recommendations and confirming that bridges have correct load ratings that account for deterioration.

Recommendations

To the American Association of State Highway and Transportation Officials:

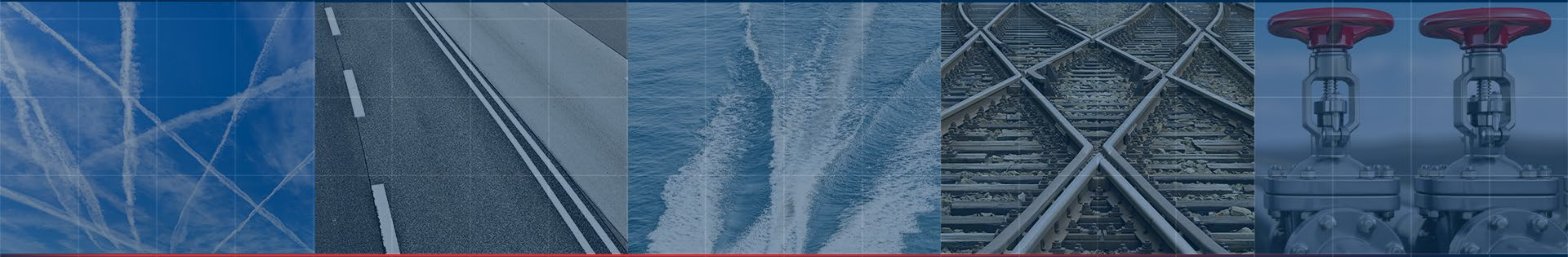
10. Update your *Manual for Bridge Evaluation* to include guidance that addresses the identification of localized tension zones and tension components in nonredundant steel members that are generally considered to be fully or partially in compression.
11. Update your *Manual for Bridge Evaluation* to include reference material on the selection, frequency of use, and application of non-destructive inspection methods for assessing the wearing surface thickness on bridge decks.

Previously Issued and Classified Recommendation

To the Federal Highway Administration:

H-23-13

Develop a risk-based, data-driven process and encourage its use by state Departments of Transportation, as well as highway-bridge-owning federal agencies and tribal governments, to help them identify, prioritize, and perform follow-up actions documented in inspections of bridges with uncoated weathering steel components.



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