February 21, 2024 Highway Investigation Report HIR-24-02

Collapse of the Fern Hollow Bridge

Pittsburgh, Pennsylvania
January 28, 2022

Abstract: On Friday, January 28, 2022, about 6:37 a.m. eastern standard time, the Fern Hollow Bridge, which carried Forbes Avenue over the north side of Frick Park in Pittsburgh, Allegheny County, Pennsylvania, experienced a structural failure. As a result, the 447-foot-long bridge fell about 100 feet into the park below. At the time of the collapse, a 2013 New Flyer articulated transit bus, operated by the Port Authority of Allegheny County, and four passenger vehicles were on the bridge. A fifth passenger vehicle drove off the east bridge abutment after the collapse began and came to rest on its roof on the ground below. As a result of the collapse, the bus driver sustained minor injuries and two bus occupants were uninjured. Of the six passenger vehicle occupants, two sustained serious injuries, one sustained a minor injury, two were uninjured, and the injury status of one was unknown. The safety issues addressed in this report include the lack of action on repeated recommendations from bridge inspection reports, including the City of Pittsburgh's (City) failure to maintain and repair the Fern Hollow Bridge and the Pennsylvania Department of Transportation's (PennDOT) failure to ensure that the City completed the maintenance and repairs specified in the recommendations from the bridge inspection reports; PennDOT's ineffective bridge inspection program, which used bridge inspection methods and measures that were noncompliant with Federal Highway Administration (FHWA) and American Association of State Highway and Transportation Officials guidance, failed to identify all of the bridge's fracture-critical members, and produced inaccurate bridge load rating calculations; and insufficient oversight by the City, PennDOT, and the FHWA of their responsibilities within the bridge inspection program to detect and prevent bridge failures. The NTSB issues new safety recommendations to the FHWA, PennDOT, the City, and the American Association of State Highway and Transportation Officials. The NTSB also classifies one previously issued recommendation to the FHWA.

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Acronyms and Abbreviations

3D	three-dimensional
AASHTO	American Association of State Highway and Transportation Officials
B1L	northwest leg of Fern Hollow Bridge
B1R	southwest leg of Fern Hollow Bridge
B2L	northeast leg of Fern Hollow Bridge
B2R	southeast leg of Fern Hollow Bridge
BIRM	*Bridge Inspector's Reference Manual*
CFR	*Code of Federal Regulations*
City	City of Pittsburgh
CS	condition state
DOMI	City of Pittsburgh Department of Mobility and Infrastructure
FCM	fracture-critical member
FE	finite element
FHWA	Federal Highway Administration
GPR	ground-penetrating radar
MBE	*Manual for Bridge Evaluation*
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NDE	non-destructive evaluation
NSTM	nonredundant steel tension member
NTSB	National Transportation Safety Board
PCA	plan of corrective action
PennDOT	Pennsylvania Department of Transportation
PY	performance year
QA	quality assurance

QC	quality control
U.S.C.	*United States Code*
UWS	uncoated weathering steel

Glossary of Bridge-Related and Other Terms

Terms italicized at first mention within definitions are included in this glossary. Any terms taken from the Federal Highway Administration's (FHWA) *Bridge Inspector's Reference Manual* are denoted with "*BIRM*" (FHWA 2023a). Terms taken from Title 23 *Code of Federal Regulations (CFR)* 650.305 are denoted with "*CFR*."

Axial load: *Compression* or *tension* force acting in a structural *member*.

Abutment: A structure designed to support the vertical and lateral forces from the ends of an arch or *span*, such as a bridge. In the case of the Fern Hollow Bridge, the abutments also acted as retaining walls.

Bent: For the Fern Hollow Bridge, there were two bents, each of which consisted of two bridge legs, *cross-bracing*, and the legs' corresponding *thrust blocks*.

Bracket: A projecting support fixed upon two intersecting members to strengthen and provide rigidity to the connection (*BIRM*).

Buckling: A *failure* by an inelastic change in alignment (deflection) as a result of compression in *axial-loaded* members (*BIRM*).

Channel: A bed where a natural stream of water runs.

Compression: A type of stress involving pressing together, which tends to shorten a member; the opposite of tension (*BIRM*).

Core: A cylindrical sample of material removed from a bridge component for the purpose of destructive testing to determine the condition of the component (*BIRM*).

Cross-bracing: A system of secondary members that maintains the geographic configuration of primary members *(BIRM*). The Fern Hollow Bridge included horizontal cross-bracing connecting the left and right bridge legs: an upper cross-brace connecting the upper ends of the legs to the midpoints of the adjacent legs within the same *bent*, and a lower cross-brace connecting the lower end of the legs to the midpoints of the adjacent legs within the same bent.

Culvert: Any structure not classified as a bridge that provides an opening under a roadway.

Dam seal: A rubber or neoprene seal over an *expansion dam*.

Dead load: The total weight of the various structural members and any objects permanently attached to the structure.

Deck: The portion of a bridge that provides direct support for vehicular and pedestrian traffic, supported by the *superstructure* (*BIRM*).

Decking: Bridge flooring installed in *panels* (*BIRM*).

Delta frame: A superstructure design type with two or more *girders* running the length of the bridge and two angled legs connected to each girder, giving the appearance of a downward pointing triangle.

Diaphragm: Bracing that extends between the girders of a bridge and assists in the distribution of *loads*; see also cross-bracing (*BIRM*).

Downspout: A pipe to carry rainwater or snowmelt from a higher elevation to ground level.

Element: See member.

End plate: A plate that distributes the compression pressure uniformly at the end of a structural component.

Expansion dam: A steel device in a bridge deck that allows the bridge to expand and contract as temperatures change, and that allows for rotation as the bridge deflects under traffic loads; also referred to as an expansion joint.

Failure: A condition at which a structure reaches a limit state such as cracking or deflection where it is no longer able to perform its usual function; collapse; *fracture* (*BIRM*).

Field splice: A location on a bridge where segments are connected during construction. The girders on the Fern Hollow Bridge consisted of five fabricated segments that were field-spliced using bolts.

Flanges: Steel plates that are separated by a *web*. Flanges, which are typically thicker and more robust than web plates, are designed to resist the bending forces in a member.

Floor beam: A primary horizontal member located *transversely* to the general bridge alignment (*BIRM*).

Floor system: The complete framework of members supporting the bridge *deck* and the traffic loading (*BIRM*).

Fracture: A rupture in tension causing partial or complete separation of a bridge member.

Fracture-critical member: A bridge component that meets three criteria: (1) it is made of steel, (2) it is fully or partially in tension, and (3) failure of the component would likely cause the bridge to partially or fully collapse. In 2022, the FHWA changed this term to *nonredundant steel tension member*.

Frame: A structure that transmits bending moments from the horizontal beam member through rigid joints to vertical or inclined supporting members (*BIRM*).

Frame line: A girder that runs the length of a bridge and its associated support legs. The Fern Hollow Bridge had two frame lines: one consisted of the southwest leg (B1R), the south girder, and the southeast leg (B2R); and the other consisted of the northwest leg (B1L), the north girder, and the northeast leg (B2L).

Girder: A horizontal structural member supporting vertical loads. Larger girders are typically made of multiple metal plates that are *welded* or riveted together. For the Fern Hollow Bridge, a girder ran the length of the bridge on both the north and south sides.

Gusset plate: A metal plate used to unite multiple structural members and hold them in the correct position at a joint (*BIRM*).

Inspection report: The document that summarizes the bridge inspection findings and recommendations as well as identifies the team leader responsible for the inspection and report (*CFR*).

***K*-factor:** The effective length factor used to account for the unbraced length of a column and its ability to resist *buckling*.

K-frame: A superstructure design type with two or more girders running the length of the bridge and two angled legs connected to each girder, giving the appearance of the letter “K” if resting on its side.

Knee brace: A short member engaging at its ends two other members that are joined to form a right angle or a near-right angle to strengthen and stiffen the connecting joint (*BIRM*).

Lamellar corrosion: Slow damage or destruction of a material by chemical action that occurs in thin layers; also referred to as exfoliation corrosion.

Legal load: The maximum load for each vehicle configuration, including the weight of the vehicle and its payload, permitted by law for the state in which the bridge is located (*CFR*).

Live load: Non-permanent loads typically in the form of vehicular or pedestrian traffic crossing the bridge.

Load: Force applied to a structure (*BIRM*); see also *axial load*, *dead load*, *legal load*, and *live load*.

Load path redundancy: A *redundancy* that exists based on the number of primary load-carrying members between points of support, such that fracture of the cross-section at one location of a member will not cause a portion of or the entire bridge to collapse (*CFR*).

Load posting: Regulatory signs installed in accordance with 23 *CFR* 655.601 and state or local law which represent the maximum vehicular live load that the bridge may safely carry (*BIRM*, *CFR*).

Load rating: The analysis to determine the safe vehicular live load-carrying capacity of a bridge using bridge plans and supplemented by measurements and other information gathered from an inspection (*CFR*). This rating is used to determine whether specific legal or overweight vehicles can safely cross the structure, whether the structure requires a *load posting*, and the level of load posting required.

Member: An individual angle, beam, plate, or built component piece intended ultimately to become an integral part of an assembled *frame* or structure (*BIRM*).

Milling: The mechanical removal of a *wearing surface*, typically accomplished by grinding, so that a new layer can be applied.

Nominal thickness: The thickness of a bridge member, such as a *flange*, web, or *tie plate*, as specified in the design plan for the bridge.

Nonredundant steel tension member: Referred to as *fracture-critical member* until 2022; a primary steel member fully or partially in tension, and without *load path redundancy*, system redundancy, or internal redundancy, whose failure may cause a portion of or the entire bridge to collapse (*CFR*).

Pack rust: Rust forming between adjacent steel surfaces in contact which tends to force the surfaces apart due to the increase in material volume (*BIRM*).

Panel: A portion of a bridge web between adjacent transverse *stiffeners*.

Patina: A dense and adherent protective rust layer that is developed during alternating wet and dry weather cycles and that resists corrosion.

Quality assurance: The use of sampling and other measures to assure the adequacy of *quality control* procedures in order to verify or measure the quality level of the entire bridge inspection and *load rating* program (*BIRM*, *CFR*).

Quality control: Procedures that are intended to maintain the quality of a bridge inspection and load rating at or above a specified level (*BIRM*, *CFR*).

Redundancy: The capability of a bridge structural system to carry loads after damage to, or the failure of, one or more of its members.

Restraint: Measures that prevent lateral movement of superstructures.

Retrofit cable: One of the cables added to the Fern Hollow Bridge to compensate for the reduced ability of the bridge to handle lateral wind loading after deterioration of the cross-bracing.

Rigid frame: A bridge with moment-resisting joints between the horizontal portion of the superstructure and vertical or inclined legs (*BIRM*).

Scupper: An opening in the deck of a bridge to provide means for water accumulated upon the roadway surface to drain (*BIRM*).

Section loss: A loss of metal, usually resulting from corrosion, that reduces the thickness of a steel bridge component. 100% section loss refers to a hole through a particular area.

Shoe: For the Fern Hollow Bridge, the trapezoidal-shaped portion at the bottom of the leg that contained the *toe*, bearing stiffeners, transverse tie plate, and portions of the web and flange below the transverse tie plate.

Sidewall: The joint interface between a weld bead and a structural *element*. If a weld shows lack of fusion to a sidewall, this indicates that the weld did not sufficiently penetrate the base metal of the structural element.

Span: The horizontal space between two supports of a structure.

Stiffener: A structural steel shape, such as a plate or an angle, that is attached to a flat plate such as the flange or web of a member, or to a *gusset plate* to add resistance to *buckling*. Stiffeners are frequently identified by position or function (for example, lateral, longitudinal, bearing, transverse).

Stringer: A beam aligned with the length of a *span* that transfers the loads from the deck to the *floor beams*.

Substructure: Bridge structure that supports the superstructure and transfers loads from it to the foundation; main components are *abutments*, piers, footings, and pilings.

Superstructure: Bridge structure that receives loads from the deck, such as traffic or pedestrian loads, and, in turn, transfers those loads to the *substructure*.

Tensile strength: The maximum tensile stress at which a material pulls apart or fails (*BIRM*).

Tension: Stress that tends to pull material apart (*BIRM*); the opposite of compression.

Thrust block: A structural element whose purpose is to transmit forces from the supported structure to the surrounding/underlying ground. This term is typically used when the forces are entering the ground at an angle (as in the case of the Fern Hollow Bridge) and the ground is expected to resist both vertical and horizontal (or "thrust") forces.

Tie plate: Also referred to as transverse tie plate; a relatively short, flat member that carries tension forces across a transverse member. For the Fern Hollow Bridge, the tie plate resisted tensile forces between the flanges at the top of the *shoe*.

Toe: For the Fern Hollow Bridge, the solid steel end cap at the bottom of the shoe that focused and transmitted the forces from the bridge leg to the thrust block.

Transverse: Perpendicular to the longitudinal (long-direction) axis. Transverse members, such as the transverse tie plate and transverse stiffeners on the Fern Hollow Bridge, help distribute stresses and improve strength and rigidity.

Uncoated weathering steel: A group of steels with carbon content of less than 0.2% by weight, to which a small percentage of alloying elements are added. One of the characteristics of this type of steel is its ability to form a *patina*.

Wearing surface: The topmost layer of material applied atop the bridge deck to provide a smooth riding surface and protect the deck from the effects of traffic and weathering.

Web: The portion of a steel shape that connects the two flanges and is oriented perpendicular to both flanges. A web is also referred to as "web plate" when referring to built-up shapes.

Weld: A joint between pieces of metal at faces that have been made plastic and caused to flow together by heat or pressure. A “fillet weld” is a weld of triangular or fillet-shaped cross-section between two pieces at right angles (*BIRM*).

Executive Summary

What Happened

On Friday, January 28, 2022, about 6:37 a.m. eastern standard time, the Fern Hollow Bridge, which carried Forbes Avenue over the north side of Frick Park in Pittsburgh, Allegheny County, Pennsylvania, experienced a structural failure. As a result, the 447-foot-long bridge fell about 100 feet into the park below. The collapse began when the transverse tie plate on the southwest bridge leg failed due to extensive corrosion and section loss. The corrosion and section loss resulted from clogged drains that caused water to run down bridge legs and accumulate along with debris at the bottom of the legs, which prevented the development of a protective rust layer or patina. Although repeated maintenance and repair recommendations were documented in many inspection reports, the City of Pittsburgh (City) failed to act on them, leading to the deterioration of the fracture-critical transverse tie plate and the structural failure of the bridge. At the time of the collapse, a 2013 New Flyer articulated transit bus, operated by the Port Authority of Allegheny County, and four passenger vehicles were on the bridge. A fifth passenger vehicle drove off the east bridge abutment after the collapse began and came to rest on its roof on the ground below. As a result of the collapse, the bus driver sustained minor injuries and two bus occupants were uninjured. Of the six passenger vehicle occupants, two sustained serious injuries, one sustained a minor injury, two were uninjured, and the injury status of one was unknown.

What We Found

We found that the southwest leg and transverse tie plate of the Fern Hollow Bridge, an uncoated weathering steel bridge, did not have the structural capacity to carry the bridge's load at the time of the collapse because they had sustained extensive corrosion and section loss. Although maintenance and repair recommendations were repeatedly made in the bridge inspection reports, the City failed to act on several of these recommendations, which led to progressive deterioration and the collapse of the bridge. We found that the Pennsylvania Department of Transportation's (PennDOT) insufficient oversight of the City's bridge inspection program contributed to the bridge's continued deteriorated condition that led to the collapse.

We also found that the bridge inspections performed by PennDOT contractors on behalf of the City were not in compliance with the Federal Highway Administration (FHWA) and American Association of State Highway and Transportation Officials (AASHTO) published guidance, and because the bridge was not properly evaluated, it remained open until its collapse. The legs of the bridge were not correctly identified in fracture-critical member plans by PennDOT contractors as fracture-critical members, and as a result, they did not undergo more in-depth, hands-on inspections.

During the on-site investigation, we found that the thickness of the bridge's asphalt wearing surface was nearly double the amount indicated in the inspection reports. Further, had the calculations and assumptions used in the bridge's load rating accounted for the correct thickness of the asphalt wearing surface, used the correct *k*-factor to estimate the axial load capacity of the bridge legs, and accounted for the localized effects of section loss on the southwest leg, this load rating calculation for the Fern Hollow Bridge would have caused the City to close the bridge.

We found that the City, in response to its failure to maintain the bridge which resulted in the bridge's collapse, made several postcollapse changes that have the potential to address the deficiencies identified in this investigation. We also found that PennDOT revised several of its policies and procedures in response to the collapse of the Fern Hollow Bridge. These revisions also have the potential to improve the identification of at-risk bridges in the future, 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. We found that in response to National Transportation Safety Board (NTSB) Safety Recommendation H-23-13, the FHWA has developed a data-driven process and encouraged its use by state departments of transportation and other bridge owners to help them identify, prioritize, and perform follow-up actions documented in inspections of bridges with uncoated weathering steel components. Finally, we found that the FHWA's data-driven reviews of targeted bridge populations should be used to investigate specific bridge safety issues such as the validity of load ratings of bridges with advanced deterioration.

We determined 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 PennDOT of the City's bridge inspection program.

What We Recommended

As a result of this investigation, we issued 11 new recommendations and classified a previously issued recommendation. We asked PennDOT to lead the effort, and the City to work with PennDOT, to evaluate the effectiveness of the changes made by the City—including completing necessary bridge maintenance and repair recommendations and confirming that bridges have correct load ratings that account for deterioration—to ensure that bridges are safe for the traveling public. We also asked PennDOT to develop and implement a plan to publish yearly aggregate data on bridge maintenance and repair recommendations to monitor the completion of these recommendations. We issued a recommendation to the FHWA to 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 to incorporate the results of these reviews into the *National Bridge Inspection Program Compliance Review Manual* as necessary.

We also issued a recommendation to the FHWA to incorporate the findings of the Fern Hollow Bridge collapse investigation into its bridge inspection training courses and to 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.

We issued one new recommendation to the FHWA to require state departments of transportation and other bridge owners to conduct a one-time review of the existing fracture-critical member (nonredundant steel tension member) inspection plans for bridges with nonredundant steel bridge 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. We issued additional recommendations to the FHWA and AASHTO to update guidance in their published manuals 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.

We asked the FHWA to update its *Bridge Inspector's Reference Manual* and bridge inspection training courses, as well as AASHTO to update its *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. We asked the City to establish a system to ensure that it maintains paving records indicating how much asphalt wearing surface is removed and how much is subsequently placed during every bridge resurfacing operation.

NTSB Safety Recommendation H-23-13 directed the FHWA to develop a risk-based, data-driven process and encourage 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. We are classifying Safety Recommendation H-23-13 as Closed—Acceptable Action.

1 Factual Information

1.1 Collapse Narrative

On Friday, January 28, 2022, about 6:37 a.m. eastern standard time, the Forbes Avenue Bridge Over Fern Hollow (referred to in this report as the Fern Hollow Bridge) in Pittsburgh, Allegheny County, Pennsylvania, experienced a structural failure.[1] As a result, the 447-foot-long bridge fell about 100 feet into the park and onto the walking path below (see figure 1).[2] The Fern Hollow Bridge was located on the north side of Frick Park, about 5 miles east of the downtown area of Pittsburgh, Pennsylvania, as shown in figure 2. At the time of the collapse, it was dark, and the temperature was 26°F with light snow.

Figure 1. West-looking view of collapsed Fern Hollow Bridge.

[1] Visit ntsb.gov to find additional information in the public docket for this NTSB accident investigation (case number HWY22MH003). Use the CAROL Query to search safety recommendations and investigations.

[2] The inspection reports for the Fern Hollow Bridge indicated that it was 447 feet long; however, the construction plan for the bridge showed the length from the centerline of one abutment to the centerline of the other abutment as 442 feet, 8 inches. The additional length in the inspection reports accounts for portions of the structure that extended beyond those centerlines.

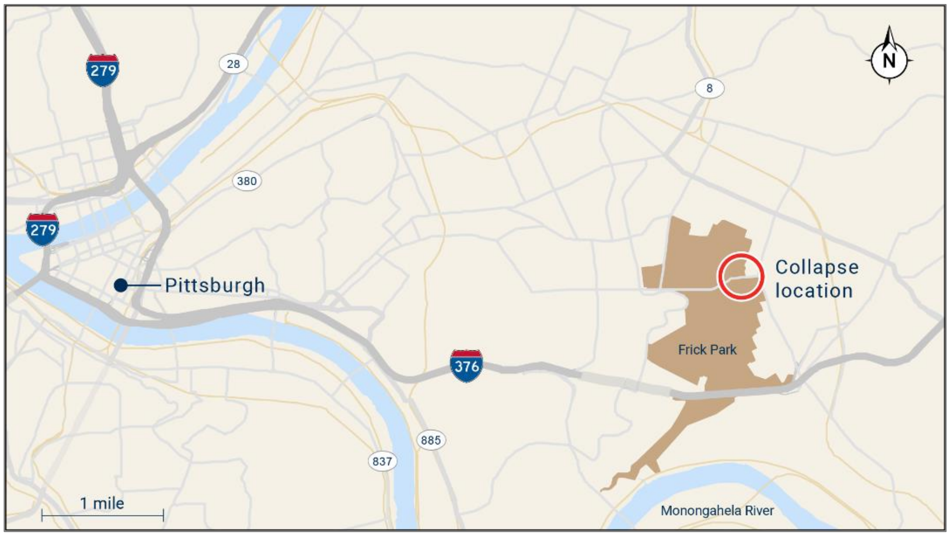

Figure 2. Map of collapse location. (Source: Google Maps; modified by the National Transportation Safety Board)

A 2013 New Flyer articulated transit bus, operated by the Port Authority of Allegheny County, and four passenger vehicles were on the bridge at the time of the collapse.[3] The bus, occupied by the driver and two passengers, as well as a 2015 Subaru Outback, a 2013 Hyundai Sonata, and a 2020 Hyundai Venue, each occupied by a driver, were traveling east. A 2011 Ford F-150, occupied by the driver and one passenger, was traveling west. A fifth passenger vehicle, a 2012 Toyota Corolla occupied by a driver and traveling west, drove off the east bridge abutment after the collapse had begun and came to rest on its roof on the ground below. The traffic volume on the bridge at the time of the collapse was lighter than normal due to the weather and related school delays. As a result of the collapse, the bus driver sustained minor injuries and two bus occupants were uninjured. Of the six passenger vehicle occupants, two sustained serious injuries, one sustained a minor injury, two were uninjured, and the injury status of one was unknown.

The transit bus was equipped with two outward-facing cameras: one was located on the right side of the bus (curbside) above the loading door and recorded video that pointed toward the rear of the bus, and the other was located above the bus driver in the destination sign at the front of the bus and recorded forward-facing video.[4] Video footage from the curbside, rear-facing camera showed that the first

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[3] On June 9, 2022, the Port Authority of Allegheny County was rebranded as Pittsburgh Regional Transit.

[4] The transit bus was equipped with a total of seven surveillance cameras: two outward-facing and five inward-facing. The video files were downloaded by Pittsburgh Regional Transit police, and the footage from the outward-facing cameras showing the collapse of the bridge was analyzed by the National Transportation Safety Board. The video footage from the inward-facing cameras did not show the collapse.

visible vertical drop in the bridge began on the west side. Although difficult to see in a still image, the south-side railing began to drop downward (see figure 3, picture A).[5] At this point, the bus was approaching the center of the bridge with the rear of the bus located about one-third of the way across the bridge. The forward-facing camera showed that at around the same time, the east end of the bridge was still intact (see figure 3, picture B); however, the camera had also just begun to pitch upward, corresponding to the rear of the bridge dropping downward. As the videos progressed, the west side of the bridge could be seen to be collapsing, followed by the east side of the bridge. Figure 3, picture C, from the curbside, rear-facing camera shows that, within less than 2 seconds, the west end of the bridge had fallen off its abutment and the south-side bridge railing had broken. About 0.5 seconds later, after the west end of the bridge had fallen (picture C) and about 2 seconds after the initial indication of the collapse (picture A), the east end of the bridge began to drop vertically down, as indicated by the changes in the top railing and the separation of the east end of the bridge from its abutment (see figure 3, picture D).

[5] The timestamps on the video stills are expressed as device times from the videos. Times are represented as hours:minutes:seconds. To timestamp different video frames within the same second with decimals, the videos were viewed using a separate video player software (iNPUT-ACE). The timestamps do not correlate with local time.

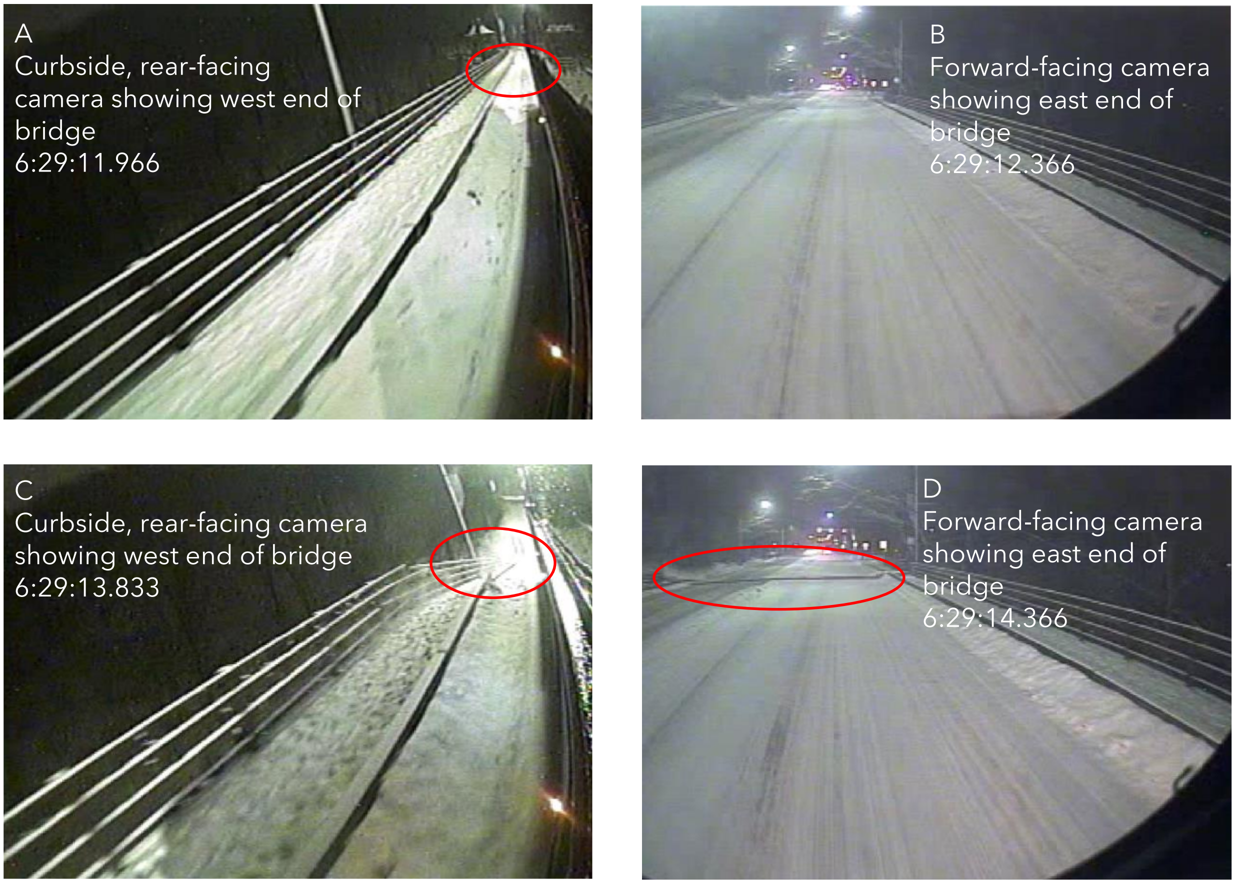

Figure 3. Video footage from Port Authority bus traveling east on the bridge. Pictures A and B show the bridge deck and railings at the initiation of the collapse. The red circle on picture A identifies the region where the first vertical drop is visible. Picture C shows that the west end of the bridge had dropped from its abutment (circled in red). Picture D shows the east side beginning to separate from its abutment (circled in red). (Source: Port Authority of Allegheny County; annotated by the National Transportation Safety Board)

As shown in figure 4, the east end of the bridge was displaced farther from the east abutment than the west end was from the west abutment at final rest. Additionally, during the collapse, a 16-inch steel, distribution main natural gas line was severed, and gas was released. No fire or explosion occurred.[6]

[6] For a flammable gas, such as natural gas, to ignite, it must reach a specific percentage volume in air. Because natural gas is lighter than air, it tends to rise and dissipate in open, non-contained environments (such as in this case), reducing the likelihood of an explosion.

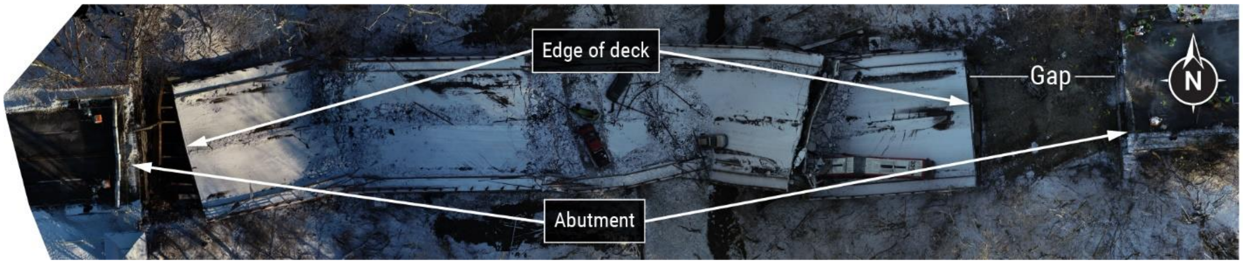

Figure 4. Overhead, orthomosaic image of collapsed Fern Hollow Bridge.

1.2 Injuries and Emergency Response

Injury information for the vehicle occupants is shown in table 1.[7] As a result of the collapse, the bus driver sustained minor injuries and two bus occupants were uninjured. Of the six passenger vehicle occupants, two sustained serious injuries, one sustained a minor injury, two were uninjured, and the injury status of one was unknown.

Table 1. Classification of injuries.

Occupant	Fatal	Serious	Minor	None	Unknown	Total
2013 New Flyer Transit Bus – Driver	0	0	1	0	0	1
2013 New Flyer Transit Bus – Passengers	0	0	0	2	0	2
2011 Ford F-150 – Driver	0	1	0	0	0	1
2011 Ford F-150 – Passenger	0	1	0	0	0	1
2015 Subaru Outback	0	0	0	1	0	1
2013 Hyundai Sonata	0	0	0	1	0	1
2020 Hyundai Venue	0	0	1	0	0	1
2012 Toyota Corolla	0	0	0	0	1	1
Total	0	2	2	4	1	9

[a] Although Title 49 *Code of Federal Regulations* (*CFR*) Part 830 pertains only to the reporting of aircraft accidents and incidents to the NTSB, section 830.2 defines fatal injury as any injury that results in death within 30 days of the accident, and serious injury as any injury that: (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date of injury; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, or tendon damage; (4) involves any internal organ; or (5) involves second- or third-degree burns, or any burn affecting more than 5% of the body surface.

According to records for the Allegheny County Department of Emergency Services, the first 911 call was received at 6:37 a.m. Police, fire, and emergency medical services for the City of Pittsburgh (City) were dispatched at 6:40 a.m. and

[7] Injury information is from the City of Pittsburgh Bureau of Police Investigation Report. Complete medical information may not be reflected in the police report.

arrived on scene at 6:45 a.m., 6:46 a.m., and 6:49 a.m., respectively.[8] All injured vehicle occupants were transported from the scene by 8:26 a.m. after emergency response personnel had extricated them from their vehicles. The gas company was notified of the broken pipe at 6:45 a.m. According to the Pennsylvania Public Utility Commission, the gas valve on the east gas line was shut off about 7:35 a.m., and the gas valve on the west side of the bridge was shut off at 8:15 a.m. As a precaution, homes in the area were evacuated by fire department personnel.

1.3 Bridge Information

1.3.1 General Description

Figure 5 shows the Fern Hollow Bridge as it was designed and opened to traffic in 1973. At the time of the collapse, the 447-foot-long, 64-foot-wide uncoated weathering steel (UWS) bridge consisted of two 11-foot-wide travel lanes in each direction (eastbound and westbound).[9] The travel lanes were flanked by 3-foot-wide shoulders and 7-foot-wide sidewalks with railings on each side of the bridge. The posted weight limit for any individual vehicle on the bridge was 26 tons (52,000 pounds), and the posted speed limit was 35 mph.[10] The transit bus had a gross weight of 43,820 pounds and the other passenger vehicles had gross weights less than 10,000 pounds each.

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[8] (a) Other emergency service agencies also responded, including Pittsburgh Regional Transit Police, the Civil Air Patrol, Allegheny County Police, and the Pittsburgh Park Rangers. (b) The president of the United States was scheduled to visit the city of Pittsburgh on the day of the collapse. Although the timing of the collapse in relation to the president's visit initially suggested the possibility that the collapse was the result of an intentional act or related to the visit of the president, agents from the Federal Bureau of Investigation and other law enforcement personnel found no evidence that this was the case.

[9] *Uncoated weathering steel* refers to a group of alloy steels that are designed to, over time and with exposure to weather, form a protective *patina* that negates the need for painting or coating.

[10] (a) A bridge's *posted weight limit*, or *load posting,* is defined in 23 *CFR* 650.305 as the regulatory signs installed in accordance with 23 *CFR* 655.601 and state or local law that represent the maximum vehicular live load that the bridge may safely carry. It indicates the maximum gross vehicle weight (including equipment being towed by the vehicle) of any individual vehicle that can safely cross the bridge. (b) The weight limit for the Fern Hollow Bridge was reduced to 26 tons in 2014 in response to a recommendation for a load rating review in the 2013 inspection report for the bridge. Additional information on the 2014 load rating evaluation can be found in section 1.12.3. Before 2014, the maximum weight for a vehicle crossing the bridge was 40 tons (80,000 pounds).

Figure 5. 1973 Fern Hollow Bridge (Source: National Steel Bridge Alliance, 1974 Prize Bridges).

The most recent traffic volume data for Forbes Avenue in the vicinity of the bridge were recorded in 2019 at just over 21,000 vehicles per day.[11] About 5.1% of these vehicles were reported to be buses and trucks.[12]

1.3.2 Bridge Design Information

The Fern Hollow Bridge was a three-span bridge with a rigid K-frame superstructure design type.[13] Two rigid frame lines ran the length of the bridge, each

[11] The traffic count was taken for Forbes Avenue between South Dallas Avenue, west of the bridge, and Briarcliff Street, east of the bridge.

[12] This percentage includes Federal Highway Administration vehicle classes 4 through 13 (buses and trucks with at least two axles and six tires); it excludes pickup, panel, and light trucks. See Glossary | PennDOT Traffic Information Repository for more information. Vehicles above the posted weight limit of 26 tons were required to obtain a special permit from Allegheny County and the state of Pennsylvania. No single-use or annual permits were issued from January 1, 2021, until the date of the collapse.

[13] A *span* refers to the parts of a bridge structure between supports. A *K-frame* design refers to a bridge with two or more girders running the length of the bridge and two angled legs connected to each girder, giving the appearance of the letter "K" if resting on its side. *Superstructure* refers to the entire portion of a bridge structure that extends across a feature (such as a river, ravine, or roadway) to carry loads from the deck across the span; the superstructure transfers those loads, through the bearings, to the bridge supports referred to as the substructure. *Substructure* refers to the component of a bridge that includes all the elements that support the superstructure; the substructure transfers the loads carried by the superstructure to the earth below.

consisting of a girder connected to two angled legs, as shown in figure 6.[14] The ends of the girders rested on the abutments. The legs, which provided intermediate support to the bridge girders, rested on foundation elements, commonly known as thrust blocks.[15] The bridge was considered to have a rigid frame because the girders and the support legs were rigidly connected and functioned as a continuous unit.

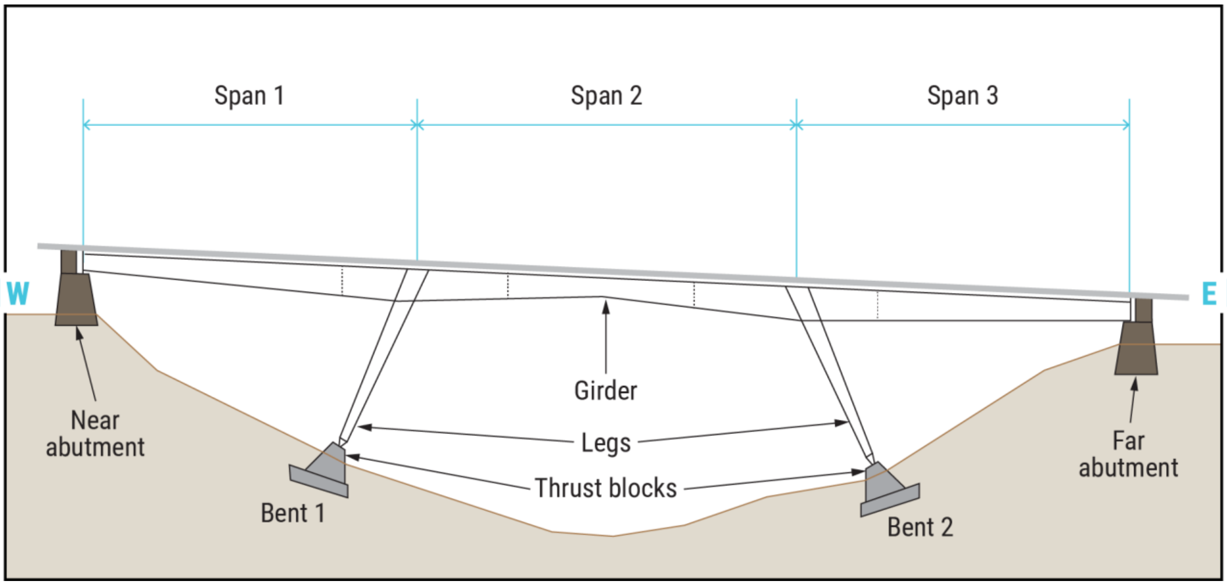

Figure 6. Simplified side (elevation) view of K-frame structure of Fern Hollow Bridge (looking north). Bents 1 and 2 were composed of two legs each; only the southwest and southeast legs are visible in this diagram.

Throughout this report, the naming and numbering conventions used to identify bridge components were adopted from the bridge inspection reports reviewed during the investigation.[16] For orientation, this report refers to the bridge structure as though the reader were standing on the west abutment (or the near abutment) and looking toward the east abutment (or far abutment).

[14] A *girder* is a horizontal structure that supports a bridge's vertical loads. In this case, the girder that ran the length of the bridge and its associated support legs constituted a frame line. For example, the southwest leg (B1R), the south girder, and the southeast leg (B2R) constituted one of the Fern Hollow Bridge's two frame lines.

[15] A *thrust block* is a structural element whose purpose is to transmit forces from the supported structure to the surrounding/underlying ground. This term is typically used when the forces are entering the ground at an angle (as in the case of the Fern Hollow Bridge) and the ground is expected to resist both vertical and horizontal (or "thrust") forces.

[16] An *inspection report*, as defined in 23 *CFR* 650.305, is the document that summarizes the bridge inspection findings and recommendations and that identifies the team leader responsible for the inspection and report.

The frame line on the north side of the bridge is referred to as being on the left, while the frame line on the south side of the bridge is referred to as being on the right. The west (or near) legs and thrust blocks, taken together with the cross-bracing between each paired leg, are referred to as the west bent (Bent 1), and the east (or far) legs, thrust blocks, and cross-bracing are referred to as the east bent (Bent 2). The four legs of the bridge can be referred to as the northwest (B1L), southwest (B1R), northeast (B2L), and southeast (B2R) legs (see figure 7). The terms "inward" or "inside" are used to indicate that a component is facing toward the longitudinal centerline of the bridge, while "outward" or "outside" are used to indicate that a component is facing toward the exterior sides of the bridge.

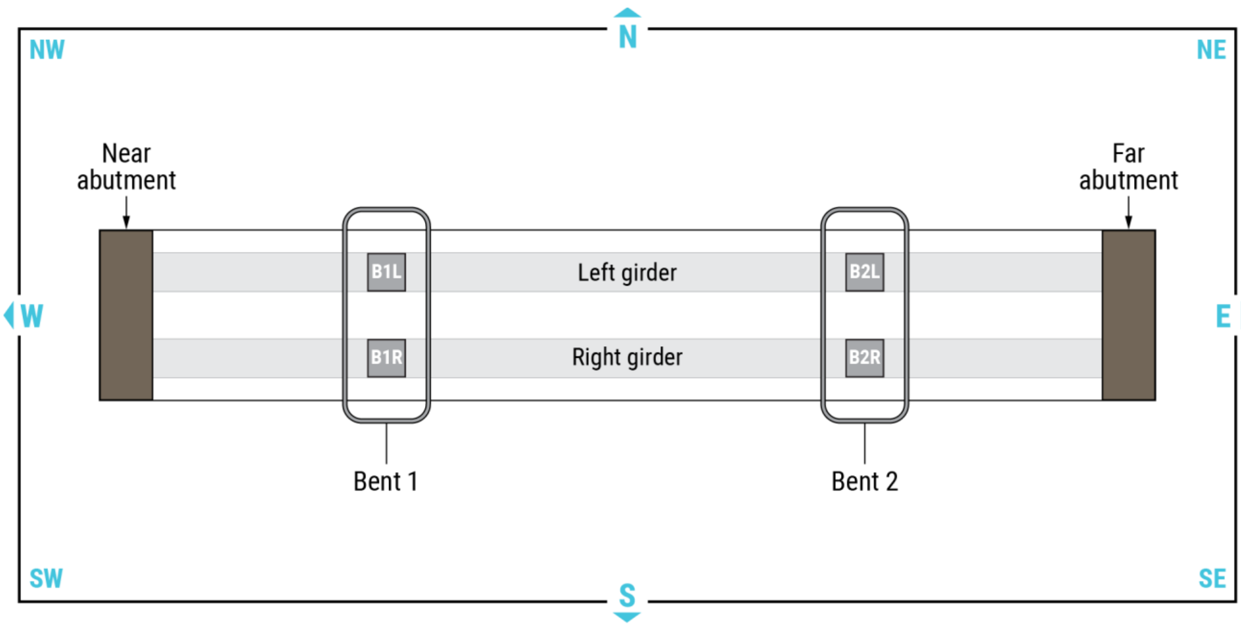

Figure 7. Simplified overhead view of bridge structure.

As with the bents, in the inspection reports the three spans and 17 floor beams were also numbered sequentially, increasing from the west (near) end of the bridge (floor beam 0) toward the east (far) end (floor beam 16), as shown figure 8. The stringers, which transferred the bridge's loads from the bridge deck to the floor beams, were oriented parallel to the girders. The floor beams, which were perpendicular to the girders and the stringers, in turn transferred the loads from the stringers to the girders.

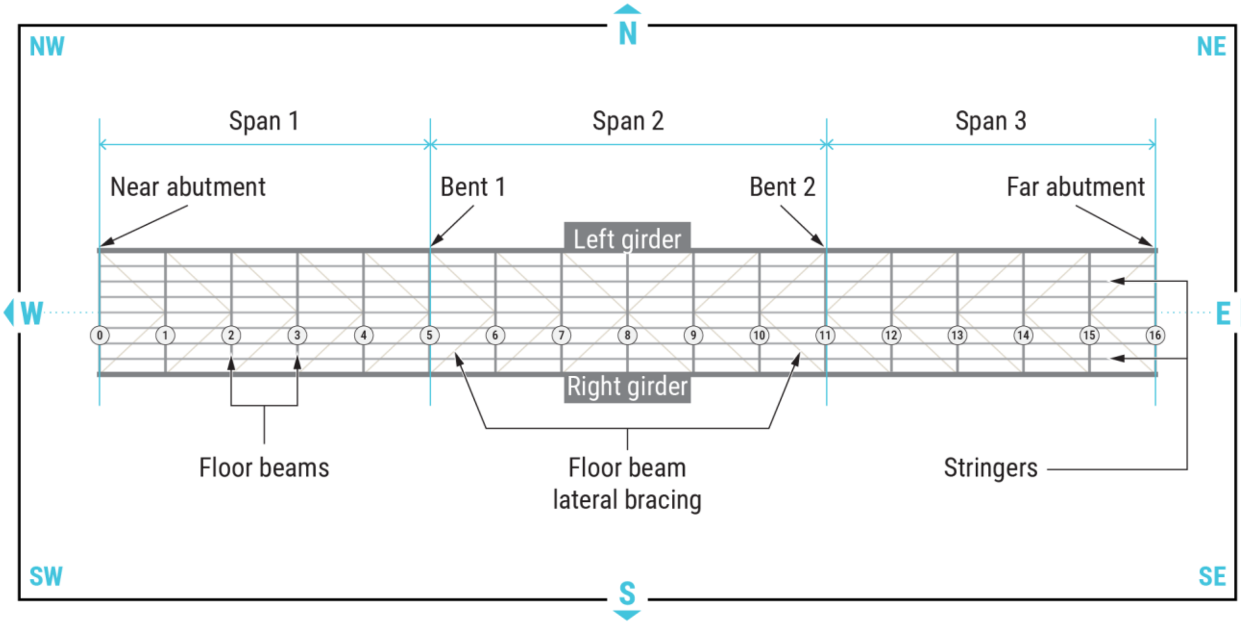

Figure 8. Overhead view of Fern Hollow Bridge showing floor beams and spans. The floor beams were numbered sequentially from left to right, with floor beam 0 positioned directly above the west (near) abutment and floor beam 16 positioned directly above the east (far) abutment.

Figure 9, a half-section diagram of the Fern Hollow Bridge, shows the asphalt wearing surface as a separate layer above the bridge deck surface. In simple terms, the asphalt surface and bridge deck were the portions of the bridge that vehicles drove over. According to the construction plans, the asphalt surface was to be 3 inches thick, and the concrete deck was to be 7.5 inches thick.

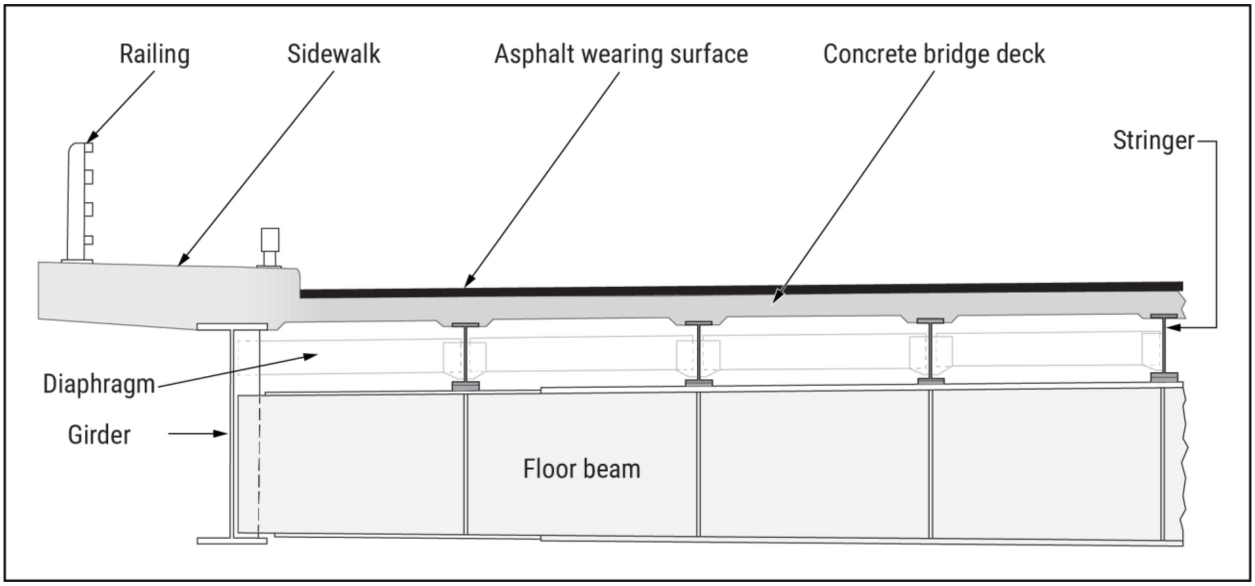

Figure 9. Half-section diagram of Fern Hollow Bridge.[17]

The 60-foot-long bridge legs were attached to the girders by bolted end plates and were inclined at 30-degree angles with respect to the vertical axis of the girder. The legs were tapered in depth, from approximately 6 feet, 10.5 inches deep at the top connection with the girder to just over 3 feet, 7 inches at the transverse tie plate located at the top of the "shoe." The shoe was the region at the bottom of the leg that tapered at a steep angle toward the thrust block (see figure 10). The shoe region was finished with an 8-inch-deep steel "toe" recessed in a 7-inch-thick steel masonry plate that was bolted to the top of the reinforced concrete thrust block.

[17] The *diaphragm* labeled in the figure is bracing that extends between the girders of a bridge and assists in the distribution of loads.

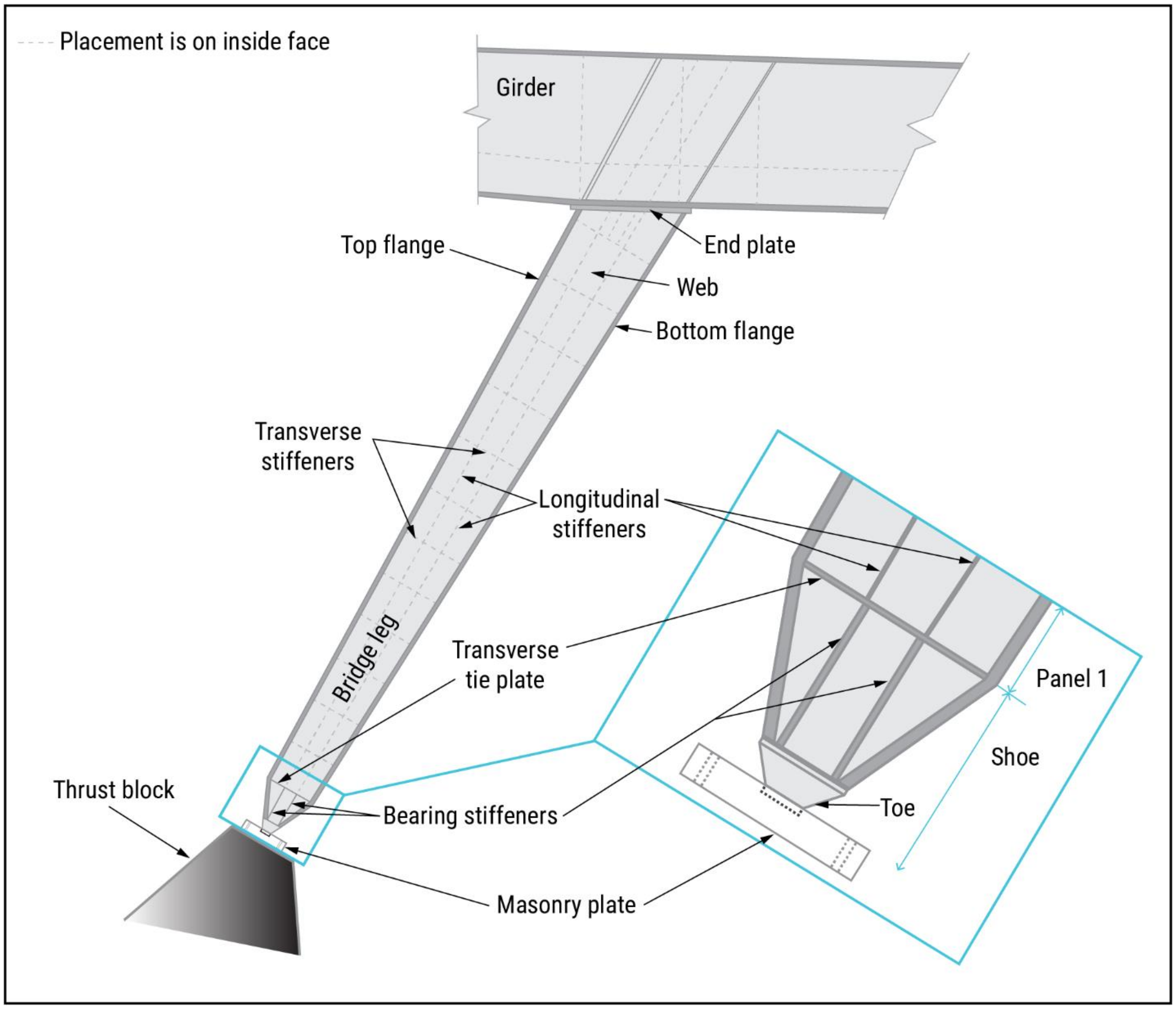

Figure 10. Inward-looking elevation view of a Fern Hollow Bridge leg and section of girder.

According to the construction plans, each bridge leg was a built-up I-shape consisting of two flanges separated by a web plate. The I-shapes were deeper and the web was thicker the farther they were from the thrust blocks. The web required both longitudinal and transverse stiffeners to resist buckling. The transverse stiffeners effectively divided the leg into 12 panels. Figure 11 shows a diagram of a generic I-shape with longitudinal and transverse stiffeners.[18]

[18] I-shaped cross-sections are typical in bridge design to resist axial, shear, and flexural loads. The I-shape is composed of two flanges at the outer extents of the section connected by a web plate oriented perpendicular to them. Because the web used in this design was relatively thin, the girder and legs required the use of longitudinal and transverse stiffeners to suppress buckling.

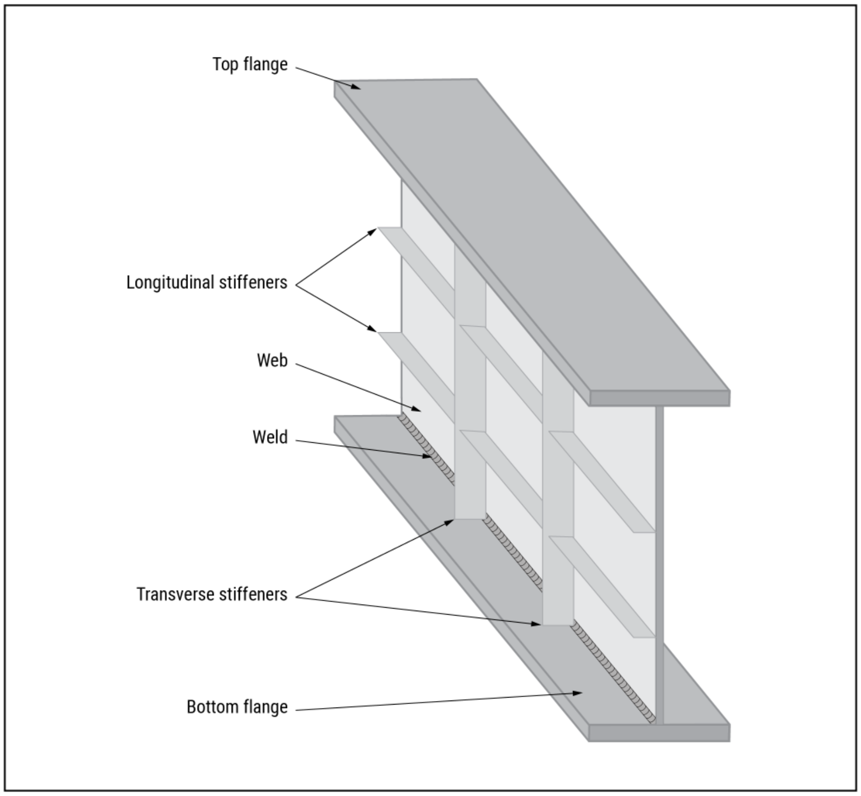

Figure 11. Diagram of generic built-up I-shape showing longitudinal and transverse stiffeners.

According to the design plan, the steel web at the lower portion of each bridge leg and each shoe was 0.5 inches thick.[19] On the inward side of each leg, the web was reinforced by longitudinal stiffeners (0.5 inches thick, according to the design plan) and transverse stiffeners (0.4375 [$^{7}/_{16}$] inches thick) along the leg length, as well as a transverse tie plate (0.75 inches thick) along the top of the shoe and bearing stiffeners (1.25 inches thick) resting atop a cast metal toe within the shoe. On the outward side, each leg had a transverse tie plate and bearing stiffeners resting atop a toe within the shoe; the portion of the web on the outward side did not have either transverse or longitudinal stiffeners.

The design of the Fern Hollow Bridge included upper and lower cross-bracing between the legs at each bent, as shown in figure 12. The upper cross-bracing connected the upper ends of the legs to the midpoints of the adjacent (north and south) legs within the same bent, and the lower cross-bracing connected the lower ends of the legs to the midpoints of the adjacent legs within the same bent. In 2009,

[19] Information from the design plan is presented here to describe the bridge as it was in its initial, built condition. Other sections of this report describe measurements of the bridge at the time of the collapse. In the Analysis section of this report, the bridge's condition as built is compared with its condition at the time of the collapse.

two steel cables were retrofitted to each of the near and far faces of the legs of each bent, forming the shape of an "X" and connecting the top of one leg to the bottom of the other leg, as shown in figure 13.[20] (See section 1.6.3 for additional information on the steel cables.)

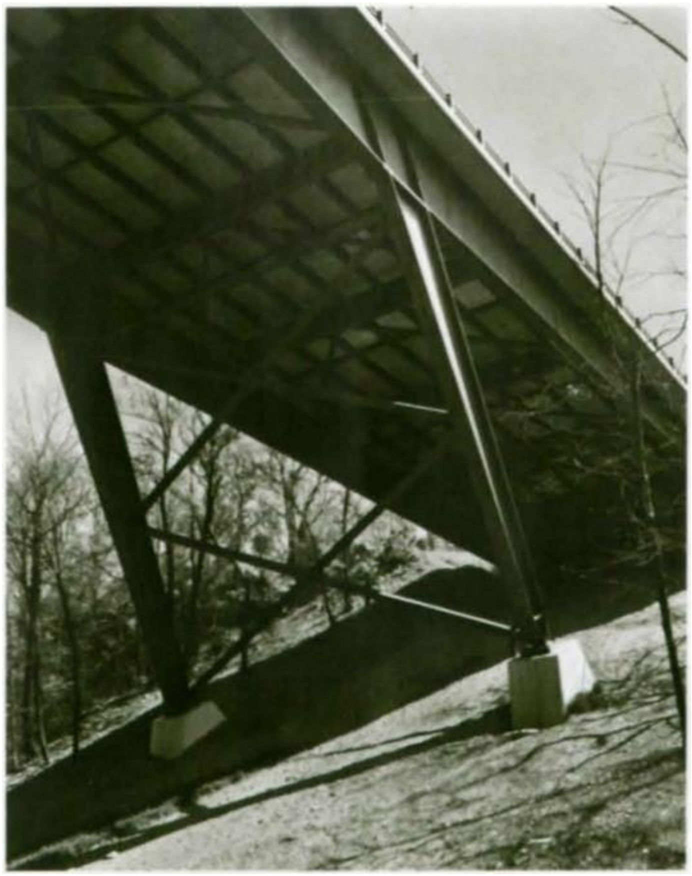

Figure 12. Bent of the Fern Hollow Bridge as originally built. (Source: National Steel Bridge Alliance, 1974 Prize Bridges)

[20] A *gusset plate* (shown in figure 13) is a metal plate used to unite multiple structural members and hold them in the correct position at a joint.

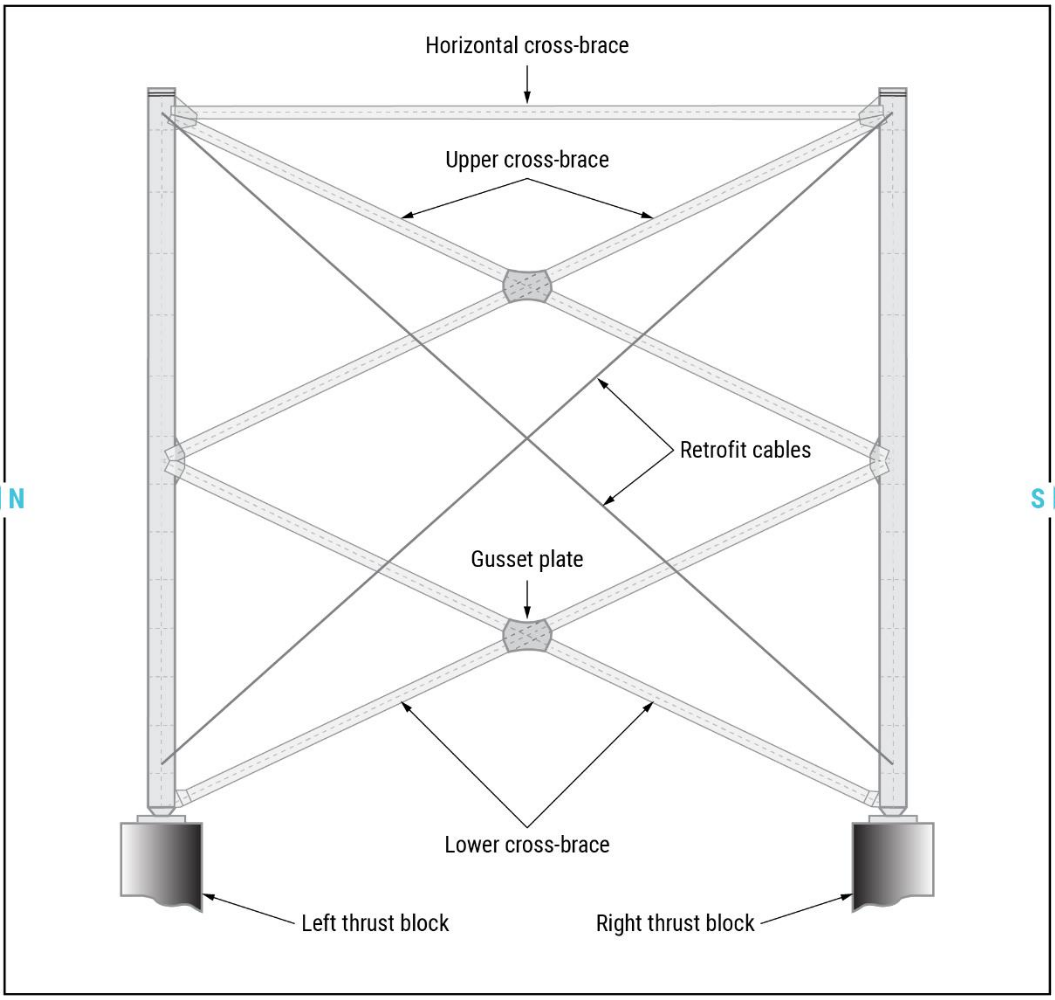

Figure 13. Elevation view of west (near) face of a Fern Hollow Bridge bent, showing original cross-bracing and retrofit cables.

1.3.3 Fracture-Critical Members

A fracture-critical member (FCM) is a bridge component that meets three criteria: (1) it is made of steel, (2) it is fully or partially in tension, and (3) failure of the member would likely cause the bridge to partially or fully collapse.[21] In 2022, the Federal Highway Administration (FHWA) renamed the term "FCM" to "nonredundant steel tension member" (NSTM) to shift the focus toward identifying members with a more severe consequence associated with sudden failure (full or partial collapse) relative to other members. The new term and expanded definition also enabled the FHWA to implement inspection procedures to identify defects that could result in

[21] (a) See 23 *CFR* 650.305. (b) Before 2022, only load path redundancy was recognized in the *CFR* for identifying an FCM. In 2022, the Federal Highway Administration broadened the types of redundancy to include load path, system, and internal redundancy.

localized failures. Finally, the new term also aimed to shift the focus away from the perception that an FCM has a higher likelihood of failure.[22]

The Fern Hollow Bridge was an FCM bridge because it had two longitudinal frame lines that were made of steel, had components in tension, and lacked load path redundancy.

1.4 Postcollapse Bridge Observations

1.4.1 Bridge Overview

This section presents additional details of the National Transportation Safety Board's (NTSB) on-scene examination of the collapsed bridge. As stated, the west ends of the girders were displaced from the west abutment and came to rest on the sloped terrain to the east of the abutment. As shown in figure 14, the bridge deck slid 5.5 feet east and 9 feet south relative to the end of the left (north) girder, and 5 feet east and 4 feet south relative to the end of the right (south) girder. The east end of the bridge was also displaced and slid about 75 feet down the embankment toward the west, away from the east abutment. The gas line at the west end of the bridge was damaged but remained connected to the abutment. The gas line at the east end of the bridge was severed (see figure 15).

[22] In this report, the term FCM is usually used when discussing the Fern Hollow Bridge. The term NSTM is used in references after 2022.

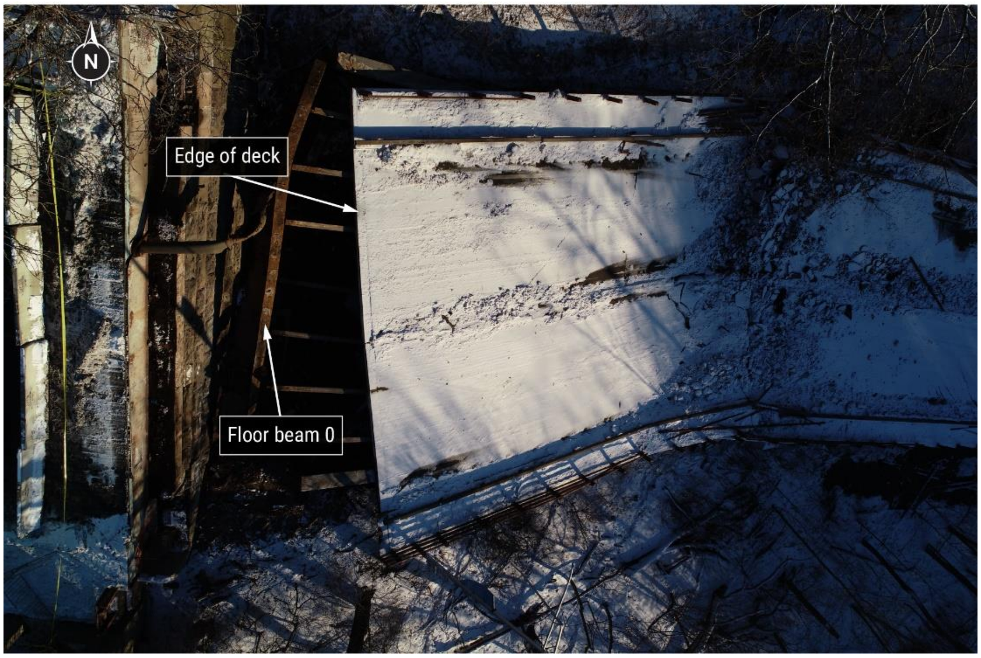

Figure 14. Overhead view of west (near) side abutment and bridge deck showing deck displacement east and south.

Figure 15. South-looking view of severed gas line at east (far) abutment.

1.4.1.1 Girders

The left and right girders were composed of five fabricated segments that were field-spliced together (connected on site) using bolts during the construction of the bridge. During the collapse, the girders experienced hinging (bending) and fracturing adjacent to the field-spliced locations.[23] The girder segments were generally intact and showed little distortion away from the splice locations. As a result, the bridge deck broke into five sections roughly corresponding to the locations of the girder segments. The thrust blocks remained intact and the steel masonry plates remained bolted to the thrust blocks.

1.4.1.2 Deck and Wearing Surface

The Fern Hollow Bridge was designed to have a 7.5-inch concrete deck slab and a 3-inch asphalt wearing surface on top of the concrete deck. The points where the bridge deck broke enabled investigators to document the concrete deck slab and wearing surface at these locations. At all examined locations, the concrete deck slab measured about 7.5 inches. On the west end of the bridge, in the area of the west (near) legs, the asphalt wearing surface thickness varied from 5.5 to 6.625 inches. On the east (far) end of the bridge deck in the area of the east (far) bridge legs, the asphalt wearing surface thickness ranged from 4.75 to 5.5 inches. Figure 16 shows the actual wearing surface after the collapse. (The term "lift" in the figure is an industry term referring to a layer of pavement placed by an asphalt paving machine.)

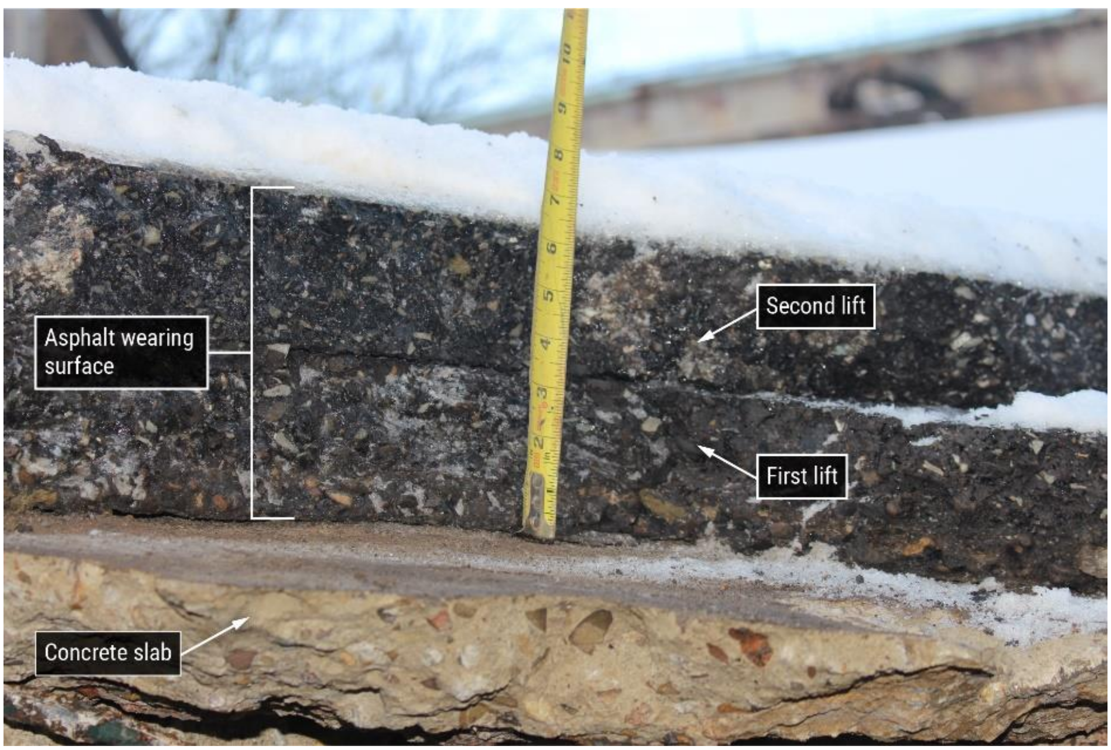

Figure 16. Photograph showing asphalt wearing surface atop reinforced concrete bridge deck in the left eastbound lane near the southwest leg.

[23] A *fracture* is a rupture in tension causing partial or complete separation of a bridge member.

1.4.2 Bridge Legs

This section describes the NTSB's postcollapse observations of the bridge legs. Corrosion and section loss were observed on each of the four legs, and section 1.7 of this report includes additional information on section loss.[24] The existing cross-bracing on the bents remained connected to the legs at a few points. (Sections 1.5.2 and 1.6.3 contain additional information on the bridge's cross-bracing.)

1.4.2.1 Northwest Leg (B1L)

The connection between the end plate at the top of the northwest leg (B1L) and the left girder remained intact. The upper and middle portions of the leg extended into the ground underneath the collapsed bridge structure. The lower portion of the leg was observed to be extending out of the ground underneath the collapsed bridge structure. After excavation, upper and lower portions of the northwest leg (B1L) were observed to have remained connected and folded back on themselves as shown in figure 17. The upper and lower portions of the leg remained connected by the web. Portions of the flanges on both sides of the leg had fractured and were no longer connected to the web, as shown in figure 18.

[24] *Section loss* refers to a reduction in cross-sectional area. In this investigation, it refers to a loss of metal, usually resulting from corrosion, that has reduced the thickness of a steel bridge component. 100% section loss refers to a hole through a particular area.

Figure 17. East-looking view of northwest leg (B1L) after excavation, folded back on itself.

Figure 18. Northwest-looking view of northwest leg (B1L) after excavation, showing that portions of the flanges on both sides were no longer connected to the web.

1.4.2.2 Northeast Leg (B2L)

The connection between the end plate at the top of the northeast leg (B2L) and the left girder remained intact. Leg B2L was fractured away from the end plate at the top of the leg, as shown in figure 19, where a large fracture near the weld on the span 3 side of the end plate is visible. Nearly the entire length of the leg below the fracture near the end plate remained intact, as shown in figure 20.

Figure 19. East-southeast–looking view of northeast leg (B2L), showing fracture from the end plate (the end plate is not visible in the photograph).

Figure 20. East-looking view of northeast leg (B2L) showing that the leg was intact below the fracture between the end plate and the top of the leg (the end plate is not visible in the photograph).

1.4.2.3 Southeast Leg (B2R)

The connection between the end plate at the top of the southeast leg (B2R) and the right girder was mostly intact, with the end plate itself being fractured and partially pulled away from the bottom flange of the girder. The lower portion of the leg (the shoe) remained intact; however, the web experienced a secondary fracture and the flanges buckled between about 3 and 12 feet above the transverse tie plate (see figure 21).

Figure 21. North-northwest–looking view of southeast leg (B2R) showing secondary fracture of the web, outlined in white.

1.4.2.4 Southwest Leg (B1R)

The connection between the end plate at the top of the southwest leg (B1R) and the south (right) girder was partially intact with several of the connecting bolts missing (see figure 22). Fractures were present at the span 1 and span 2 sides of the end plate. The lower portion of the leg was visible from underneath the collapsed bridge structure. The portion of the leg below the transverse tie plate (the shoe) was rotated back on itself just above the connection of the transverse tie plate and the flanges, as shown in figures 23 and 24. Examination of the southwest leg (B1R) after it had been removed from the ground showed that the span 2 side flange remained attached to the upper portion of the leg but was completely separated from the lower portion of the leg. This flange was curled up and was located underneath the web from the upper portion of the leg, as shown in figure 25. More extensive corrosion and section loss were observed on numerous parts of the southwest leg (B1R) than on the other three legs, including the web, lateral and longitudinal stiffeners, bearing stiffeners, transverse tie plate, and flanges.

Figure 22. North-northeast–looking view of southwest leg (B1R) end plate still partially connected to south (right) girder. Several connecting bolts and their nuts were missing (white oval).

Figure 23. East-looking view of lower portion of southwest leg (B1R) underneath the collapsed structure.

Figure 24. View of southwest leg (B1R) showing hinge above transverse tie plate and flange connection. The span 2 side flange that had been on the side of the web oriented toward the top of the photograph was completely separated from the leg.

Figure 25. Southeast-looking view of upper portion of southwest leg (B1R) showing partial separation of span 1 side flange and significant separation and curling of span 2 side flange.

1.5 Fern Hollow Bridge Inspections

1.5.1 General Bridge Inspection Information

1.5.1.1 Roles and Responsibilities

Bridges are inspected periodically to ensure that they are safe for the traveling public and to prevent structural or functional failures. Additionally, bridge owners use information collected about the condition and operation of the bridges to make informed asset management decisions. Federal, state, and city and municipal governments have roles in bridge maintenance and safety.

Title 23 *United States Code* (*U.S.C.*) Section 144 gives the FHWA, via the Secretary of Transportation, the authority to establish bridge inspection standards.[25] The standards, called the National Bridge Inspection Standards (NBIS) and contained in 23 *CFR* Part 650, Subpart C, establish definitions, responsibilities for bridge

[25] See 23 *U.S.C.* 144(h).

inspection organizations, qualifications of personnel, inspection intervals, inspection procedures, and inventory requirements.[26] The NBIS apply to all structures defined as highway bridges located on all public roads and define a bridge as a structure over a depression or an obstruction that is more than 20 feet long, having a passageway for carrying traffic or other moving loads.[27]

The FHWA is responsible for assessing the compliance of the states with the NBIS (see section 1.5.3.1 for additional information on the assessment process).[28] Other FHWA responsibilities include administering a bridge inspection training program and maintaining the National Bridge Inventory (NBI). The NBI is a database containing information collected by the states on the bridges in the United States.[29] This collected information enables national- and state-level analyses to assess the number, condition, and performance of bridges. It also supports federal funding programs and facilitates the identification of freight- and defense-critical corridors and connectors.

States are responsible for carrying out the NBIS. According to 23 *CFR* 650.307(a), states are required to "perform, or cause to be performed, the proper inspection and evaluation of all highway bridges that are fully or partially located within the state's boundaries, except for bridges that are owned by federal agencies or tribal governments." Other state responsibilities include such actions as developing and implementing bridge inspection policies and procedures; performing quality control (QC) and quality assurance (QA) activities; preparing, maintaining, and reporting bridge inventory data; and producing valid load ratings and when required, implementing load posting or other restrictions.[30]

The Pennsylvania Department of Transportation (PennDOT) is the agency in Pennsylvania with overall responsibility to ensure that all bridges in the state, including locally owned bridges, are inspected in compliance with the NBIS.[31] In Pennsylvania, municipalities (for example, cities, counties, and townships) that own bridges subject to the NBIS—such as the City—are responsible for inspecting their bridges. The City owned the Fern Hollow Bridge and therefore was responsible for

[26] The NBIS were first published in 1971 and most recently updated in 2022. The 2004 NBIS with updates from 2009 were in effect at the time of the collapse and thus were used to evaluate the inspection reports for the Fern Hollow Bridge.

[27] See 23 *CFR* 650.303, "Applicability," and 23 *CFR* 650.305, "Definitions."

[28] See 23 *U.S.C.* 144(h)(4)(A).

[29] See [Bridges & Structures: National Bridge Inventory (NBI)]() for more information.

[30] See 23 *CFR* 650.307 for the complete list of responsibilities.

[31] For additional information on locally owned bridges in Pennsylvania, see Ladyka and Wigton 2016.

inspecting it in accordance with the NBIS; however, PennDOT remained responsible for ensuring that the City had inspected the bridge in compliance with the NBIS because the ultimate responsibility for the NBIS cannot be delegated.[32]

According to the City of Pittsburgh Department of Mobility and Infrastructure (DOMI), the City has the option to conduct its own inspections (either through in-house resources or a City contract) or to have an engineering firm conduct the inspections through a PennDOT contractor. The City chose to use an inspector contracted with PennDOT District 11 for its bridge inspections, including the inspections of the Fern Hollow Bridge.[33] Although contractors are not an entity assigned responsibility under the NBIS, the scope of work contract used by PennDOT requires the contracted inspectors to completely inspect all bridge elements in accordance with the NBIS.[34] The contracted inspectors also have other duties including providing qualified personnel to perform the inspections; determining if current bridge conditions warrant a new load rating for load capacity and recommending a new load rating where appropriate; documenting the bridge condition using appropriate notes, sketches, and photographs; and recommending a prioritized and time-scheduled listing of improvement needs for maintenance, rehabilitation, and replacement.

As the owner of the Fern Hollow Bridge, the City was ultimately responsible for the safety of the bridge. In addition to performing the inspections, the City was also responsible for the maintenance and repair of the bridge. PennDOT cannot compel local owners to perform maintenance, rehabilitation, or replacement of bridges, except through the authority to close or post a reduced weight limit on a bridge. Further, the FHWA's only direct oversight authority is to oversee PennDOT in accordance with 23 *CFR* 650; it does not have oversight authority for local agencies.

1.5.1.2 Inspection Guidance

During an inspection, the condition and any change in condition of the bridge since the last inspection is documented, and deficiencies are identified. The *Bridge Inspector's Reference Manual* (*BIRM*), published by the FHWA, is a comprehensive manual including programs, procedures, and techniques for inspecting and evaluating bridges (FHWA 2023a). The FHWA updates state departments of

[32] See 23 *CFR* 650.307(f).

[33] PennDOT has 11 regional districts. Each district covers certain Pennsylvania counties and oversees programs and policies affecting highways, urban and rural public transportation, airports, railroads, ports, and waterways. See PennDOT Regional Offices for more information.

[34] (a) See PennDOT Publication 238 (PennDOT 2022a), Appendix IP 01-F, "General Scope of Work – Safety Inspection of State and Local Bridges." (b) Consultant agreement procedures and policies are outlined in PennDOT Publication 93 (PennDOT 2022b).

transportation by publishing memorandums and technical advisories containing additional bridge inspection information.[35] The *Manual for Bridge Evaluation* (*MBE*) is published by the American Association of State Highway and Transportation Officials (AASHTO) and is another resource for bridge inspection to be used along with the *BIRM* (AASHTO 2018). It provides guidance and best practices for the inspection as well as the load rating of highway bridges. The *MBE* is incorporated by reference into the *CFR*.[36]

PennDOT also publishes a *Bridge Safety Inspection Manual*, referred to as Publication 238 (PennDOT 2022a). The purpose of this manual is to compile PennDOT policies and procedures and to ensure compliance with federal and state standards. It provides guidance on the technical standards and specifications for bridge inspection as well as load rating and posting. Publication 100A, *Bridge Management System 2*, provides coding information for PennDOT's system to store bridge inventory, condition, and appraisal data (PennDOT 2022c). For example, it includes information on the priority coding of maintenance and repair recommendations, which are discussed further in section 1.5.2.

1.5.1.3 Qualifications of Bridge Inspectors

The inspectors who performed the inspections of the Fern Hollow Bridge were employed by engineering firms contracted by PennDOT.[37] Following the collapse, the FHWA verified that the team leaders who were responsible for planning, preparing, and performing the Fern Hollow Bridge inspections met the qualifications for those positions as defined in 23 *CFR* 650.309 and PennDOT policy at the time of the collapse. Team leaders could have met federal requirements through various combinations of education, experience, certifications, and completion of FHWA bridge inspection classes, as shown in Appendix C. Additionally, according to PennDOT policy, inspection personnel for state or locally owned bridges must hold a

[35] For more information, see Bridges & Structures: Bridge Inspection.

[36] See 23 *CFR* 650.317(a), "AASHTO."

[37] From 2005 through 2021, three different engineering firms were contracted by PennDOT to perform the inspections of the Fern Hollow Bridge for the City. These firms included Wilbur Smith Associates (2005–2013), CDM Smith (2014–2019), and Gannett Fleming (2020–2021).

valid certification issued by the Department.[38] Appendix C also shows the updates that were made to the team leader qualifications when the NBIS were revised in 2022.

1.5.1.4 General Information on Fern Hollow Bridge Inspections

According to the NBIS, bridges are required to undergo different types of inspections at various time intervals depending on their characteristics.[39] As shown in table 2, the Fern Hollow Bridge was subject to routine, FCM, and special (or interim) inspections. At the time of the collapse, "routine inspection" was defined as:

> Regularly scheduled inspection consisting of observations and/or measurements needed to determine the physical and functional condition of the bridge, to identify any changes from initial or previously recorded conditions, and to ensure that the structure continues to satisfy present service requirements.[40]

Routine inspections were required to be performed on the Fern Hollow Bridge at intervals not to exceed 24 months. An FCM inspection was defined as a "hands-on inspection of fracture-critical members or member components that may include visual and other non-destructive evaluation" and was also required to be performed on the Fern Hollow Bridge at 24-month intervals.[41] The contractor conducted the FCM inspections of the Fern Hollow Bridge at the same time as the routine inspections. The superstructure condition rating in 2011 was a 4, which should have qualified it for an inspection in 2012; however, no inspection was performed in 2012.

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[38] To become a certified inspector in Pennsylvania, PennDOT employees and consultants must complete PennDOT's Bridge Safety Inspector Training and Certification program. The program consists of an initial 15-day training course that addresses bridge engineering concepts, recognizing material deterioration, inspection techniques and procedures, and rating and documenting conditions of all components. A comprehensive final exam must be passed to receive a Pennsylvania certification. Team members have 12 months from the date of hire to become certified. To maintain a Pennsylvania inspection certification, inspectors are required to attend a refresher training course and pass a final exam every 2 years to remain current with new inspection technologies and procedures.

[39] 23 *CFR* 650 Subpart C defines several types of inspections. In addition to routine, FCM, and special, there are initial, in-depth, and damage inspections. In the 2022 update to the NBIS, definitions of some of the inspection types were revised, and the length of time between inspections can now be extended using specific risk-based methods (see 23 *CFR* 650.311). For example, the definition for a routine inspection is now as follows: "Regularly scheduled comprehensive inspection consisting of observations and measurements needed to determine the physical and functional condition of the bridge and identify changes from previously recorded conditions."

[40] See NBIS, Side-by-Side Comparison between Previous Regulation and Final Rule, p. 8.

[41] The definition for an NSTM inspection changed in 2022 to "a hands-on inspection of a nonredundant steel tension member."

PennDOT was not able to confirm the reason for the omission.[42] Beginning in 2014, interim FCM inspections (equivalent to "special" inspections as defined in the NBIS) were required due to the condition rating of an FCM as well as the bridge having a posted weight limit (PennDOT 2022a). Thus, the inspection frequency increased to every 12 months.[43] In March and September 2018, additional interim inspections were required due to the City's failure to complete high priority maintenance recommendations related to signage (see section 1.5.2).[44]

Table 2. Dates and types of Fern Hollow Bridge inspections, 2005 to 2021.

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

1.5.1.5 Fracture-Critical Member Identification

The *MBE* requires a written and documented inspection plan for FCM inspections, underwater inspections, and inspections of bridges with complex

[42] When asked why an interim inspection was not conducted in 2012, PennDOT indicated that the 2012 inspection may not have been performed because the component that triggered the condition rating may not have been identified as fracture-critical.

[43] (a) According to 23 *CFR* 650.305, a special (or in this case, interim) inspection is defined as an inspection scheduled at the discretion of the bridge owner, used to monitor a particular known or suspected deficiency. (b) See PennDOT 2022a, Table IP 2.3.2.4-1, "Intervals of Routine and Special Inspections for State and Local Owned Bridges > 20′ Length."

[44] See PennDOT 2022a, Table IP 2.3.2.4-1, "Intervals of Routine and Special Inspections for State and Local Owned Bridges > 20′ Length."

features. Until 2011, the inspection reports contained hand-drawn figures with notes about the FCMs. A "Fracture-Critical Identification Framing Plan," a diagram showing the locations of the members of the bridge that were identified as fracture-critical, was developed by an engineering firm contracted by PennDOT on behalf of the City and included in the Fern Hollow Bridge inspection reports beginning in 2011.[45] Figure 26 shows the 2011 Fracture-Critical Identification Framing Plan diagram with the floor beams and portions of the girders highlighted in green and identified as FCMs. This diagram was also used for the 2013 and 2015 inspection reports. In 2016, a different engineering firm, also contracted by PennDOT on behalf of the City, prepared a "Fatigue and Fracture Bridge Inspection Plan," a larger document that included a new Fracture-Critical Identification Framing Plan diagram dated December 2015.[46] The new diagram identified the floor beams and portions of the girders as FCMs and included updated notes on the floor beams and the girders. The 2015 Fracture-Critical Identification Framing Plan diagram was included in the inspection reports from 2017 through 2021. Neither the 2011 nor the 2015 Fracture-Critical Identification Framing Plan diagrams labeled the legs of the bridge as FCMs. The purpose of the Fracture-Critical Identification Framing Plan is to provide inspectors with FCM information so that they can recognize members or portions of the bridge requiring more rigorous inspection techniques. For example, the engineer who signed and sealed the Fatigue and Fracture Bridge Inspection Plan for the Fern Hollow Bridge—and who also signed and sealed the 2015, 2016, 2017, 2018, and 2019 bridge inspection reports—indicated in an interview with the NTSB that as an inspector, he relies on the Fracture-Critical Identification Framing Plan to identify the FCMs.

[45] "Fracture-Critical Identification Framing Plan" is the title appearing on the diagram. It is also referred to as the "FCM framing plan" in the 2011 inspection report.

[46] The Fatigue and Fracture Bridge Inspection Plan is a term used by PennDOT to provide a "map" of FCMs and their details on the structure to identify all fatigue-prone or fracture-critical details for the inspectors. This assures that the conditions of all critical components will be inspected adequately and that the field results will be presented in an organized manner to enable the inspection engineer to ascertain the bridge's safety in a timely manner (PennDOT 2022a).

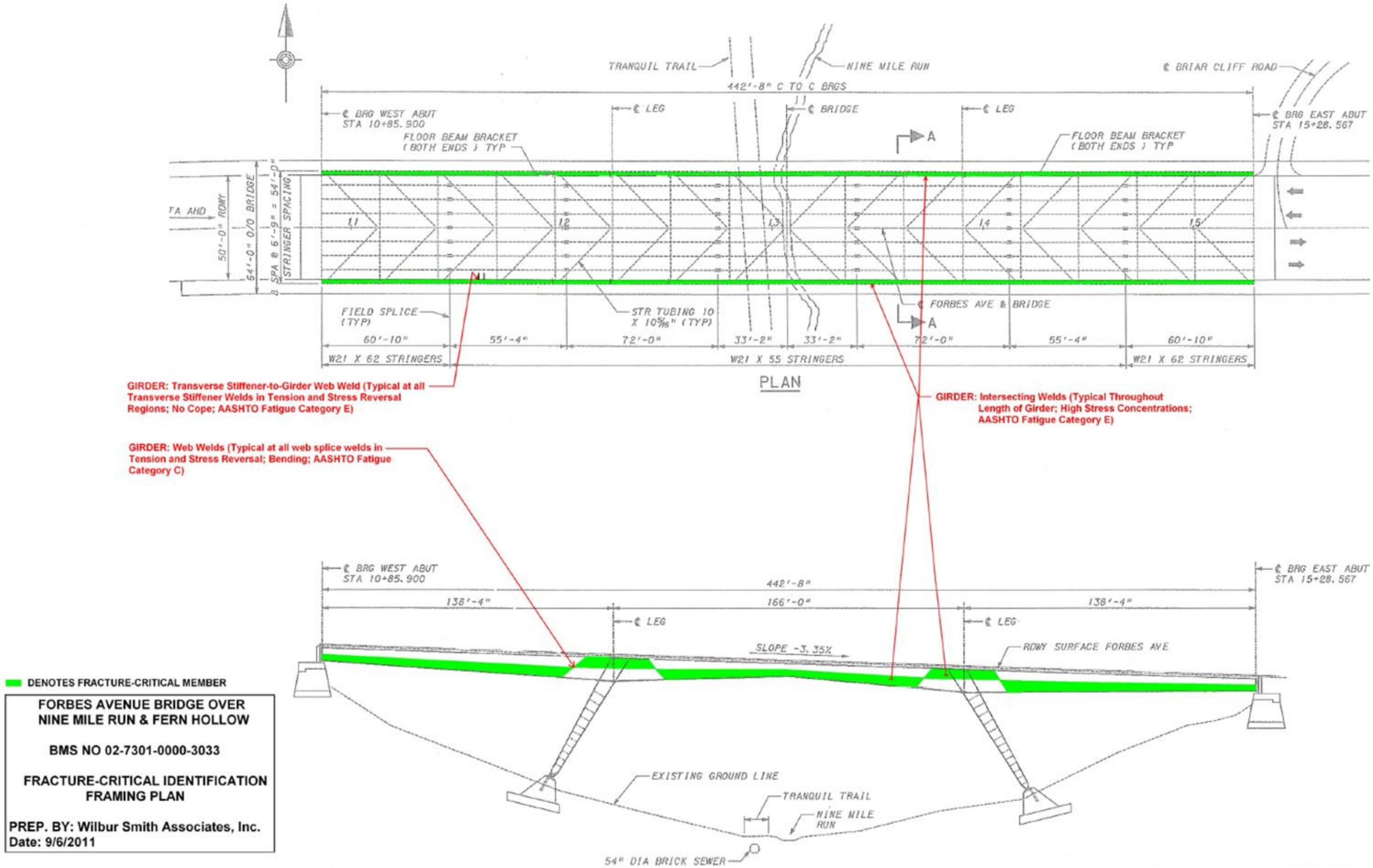

Figure 26. Fracture-Critical Identification Framing Plan developed in 2011 and included in the 2011, 2013, and 2015 inspection reports. (Source: FHWA)

1.5.2 Findings, Maintenance and Repair Recommendations, and National Bridge Inventory Ratings from Fern Hollow Bridge Inspection Reports

This section describes major and relevant findings and recommendations from the 2005 through 2021 Fern Hollow Bridge inspection reports provided to the NTSB by the City. It also notes the priority codes assigned to recommendations in accordance with PennDOT guidance (see table 3) as well as NBI ratings of the bridge in accordance with FHWA guidance (see table 4 and table 5).

PennDOT requires that recommendations from inspections be assigned a priority code on a scale from 0 (Critical) to 5 (Routine), which establishes a timeframe for work to be completed (PennDOT 2022c). Table 3 shows the priority codes and associated timeframes.

Table 3. PennDOT maintenance recommendation priority codes and timeframes for completion.

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 [a]
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 [b]	Within the Next Work Cycle

Source: PennDOT 2022c

[a] The routine inspection interval for the Fern Hollow Bridge was 24 months.

[b] In 2022, the short definition for priority code 5 (Routine) was changed to "Non-structural," and the action timeframe was changed to "can be delayed until programmed."

Condition ratings, which are used to describe the existing, in-place bridge condition as compared to the as-built condition, are captured in the NBI for the deck (item 58), superstructure (item 59), and substructure (item 60). The condition ratings are assessed on a 0 (Failed) to 9 (Excellent) scale, as shown in table 4.[47]

[47] The Fern Hollow Bridge superstructure included the girders, floor beams, stringers, diaphragms, cross-bracing, drainage system, and bridge legs. The legs of a rigid frame bridge such as the Fern Hollow Bridge are considered superstructure because they are above the bearings and act integrally with the girders. The portions of the Fern Hollow Bridge that were considered the substructure included the abutments and the thrust blocks.

Superstructure ratings, which include the bridge legs, are presented and discussed in this report.

Table 4. National Bridge Inventory condition rating.

Code	Description
N	Not Applicable
9	Excellent Condition
8	Very Good Condition – no problems noted.
7	Good Condition – some minor problems.
6	Satisfactory Condition – structural elements show some minor deterioration.
5	Fair Condition – all primary structural elements are sound but may have minor section loss, cracking, spalling or scour.
4	Poor Condition – advanced section loss, deterioration, spalling or scour.
3	Serious Condition – loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	Critical Condition – advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	"Imminent" Failure Condition – major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	Failed Condition – out of service – beyond corrective action.

Source: FHWA 1995

In addition to the general condition ratings, data on bridges are also collected at the element level.[48] Assessments at the steel element level are made using condition states (CS) ranging from CS1 indicating no defects (Good Condition) to CS4 (Severe Condition), as shown in table 5 (AASHTO 2019). Any defect in CS4 (Severe Condition) warrants a structural review to determine the effect on strength or serviceability of the bridge.

Table 5. National Bridge Inventory element condition states for steel elements.

Defects	CS1 Good	CS2 Fair	CS3 Poor	CS4 Severe
Corrosion (1000)	None.	Freckled rust. Corrosion of the steel has initiated.	Section loss is evident or pack rust is present but does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge, OR a structural
Cracking (1010)	None.	Crack that has self arrested or has	Identified crack that is not arrested but	

[48] An element-level inspection assesses the condition of the elements that make up the bridge (for example, the concrete deck, steel girders, steel floor beams, and concrete abutment) and is reported in terms of the quantities of each element found to be in each of the four CSs.

Defects	CS1 Good	CS2 Fair	CS3 Poor	CS4 Severe
		been arrested with effective arrest holes, doubling plates, or similar.	does not warrant structural review.	review has been completed and the defects impact strength or serviceability of the element or bridge.
Connection (1020)	Connection is in place and functioning as intended.	Loose fasteners or pack rust without distortion is present but the connection is in place and functioning as intended.	Missing bolts, rivets, or fasteners, broken welds, or pack rust with distortion but does not warrant a structural review.	
Distortion (1900)	None.	Distortion not requiring mitigation or mitigated distortion.	Distortion that requires mitigation that has not been addressed but does not warrant a structural review.	
Settlement (4000)	None.	Exists within tolerable limits or arrested with no observed structural distress.	Exceeds tolerable limits but does not warrant structural review.	
Scour (6000)	None.	Exists within tolerable limits or has been arrested with effective countermeasures.	Exceeds tolerable limits but is less than the critical limits determined by scour evaluation and does not warrant structural review.	
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in CS2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in CS3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in CS4 under the appropriate material defect entry.

Source: AASHTO 2019

1.5.2.1 Inspection Report Findings and Recommendations

Notable inspection findings, maintenance recommendations, and NBI superstructure ratings from each inspection report are provided in figure 27.

	2005	2007	2009	2011	2013	2014*d	2015	2016*	2017	March 2018*	September 2018*	2019	2020*	2021
Notable Inspection Findings														
Partially or fully clogged drainage inlets	•	•	a	•	•	•	•	◊	•	◊	◊	•	◊	•
Debris accumulation on surfaces of superstructure	•	•	•	•	•	•	•	•	•	◊	•	•	•	•
Water from corroded drainage system leaking directly onto Leg B1R	•	•	b											
Moderate to severe corrosion with section loss to cross-bracing between legs	•	•	•	•	•	•	•	•	•	•	•	•	•	•
All frame legs have heavy section loss on transverse stiffeners	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Areas of severe corrosion on bottom flanges of all legs		•	•	•	•	•	•	•	•	•	•	•	•	•
Structural strand cables attached to the legs lacked tension			c	•	•									
Maintenance Recommendations														
Clean clogged drainage inlets on the deck of the structure	•	•		•	•		•	◊	•	•	•	•	◊	•
Extend deck weepholes to clear the superstructure		•	•	•	•		•		•	•		•		•
Clean debris from surfaces of superstructure	•	•	•	•	•		•	•	•	◊	◊	•	◊	•
Repair downspouts that are leaking onto frame legs	•	•												
Repair cross-bracing between legs of Bent 1	•	•	•	•	•		•	•	•	•	•	•	•	•
Reinforce stiffeners/repair holes that have rusted through		•	•	•	•		•	•	•	•	•	•	•	•
Blast cleaning and painting deteriorated areas of superstructure, specifically the lower halves of the frame legs	•	•	•	•	•		•	•	•	•	•	•		•
Re-tension structural retrofit cables attached to the legs				•	•									
Guardrail repair and update to current standards	•	•	•	•	•		•	◊	•	◊	◊	•	◊	
National Bridge Inventory Condition Ratings														
Superstructure	5	5	5	4	4	4	4	4	4	4	4	4	4	4

Key:

- • The inspection finding was documented or the maintenance recommendation was listed in the indicated inspection year.
- ◊ According to the interim inspection reports, these items were not inspected in the indicated inspection year, and the previous inspection report was typically referenced for the condition of these items.
- * Interim inspections (inspections performed between routine inspection years) were, in this case, performed during the even years. The interim inspections began in 2014 after they became required under PennDOT policy due to the structure having a condition rating of 4 on a fracture-critical member and/or a posted weight limit.

Notes:

a To perform some of the rehabilitation work in early 2009, the deck drainage inlets were cleaned. The September 2009 inspection report noted that the drains remained clear of debris.

b The downspouts leading from the deck drainage inlets to the storm sewer system were replaced as part of the rehabilitation work performed in early 2009.

c The retrofit structural strand cables were installed between the frame legs in each bent as part of the rehabilitation work performed in early 2009.

d (1) No maintenance recommendations were made in the 2014 interim inspection report. (2) The September 2014 inspection report indicated that the retrofit steel cables were tightened during the summer of 2014.

Figure 27. Summary chart of findings, maintenance recommendations, and condition ratings for the Fern Hollow Bridge.

Since at least 2005, the inspection reports noted holes, or 100% section loss, in the web and section loss in the transverse stiffeners of the legs of the Fern Hollow Bridge. The 2005 report stated that the legs were in "fair to poor condition" and noted areas of 100% section loss measuring up to 2 inches by 4 inches in the southwest leg (B1R). It also noted up to 75% section loss on the transverse stiffeners on the other bridge legs. The 2007 inspection report stated that the web of the west (near) legs had severe corrosion with 100% section loss and that the transverse stiffeners had "knife edging" (thinning of material) and section loss up to 100%. The east (far) legs were reported to be in similar condition. The 2007 inspection report recommended that the stiffeners that had rusted through be reinforced; a priority code of 2 was assigned to this recommendation. In the 2009 inspection report, two holes measuring up to 2.5 inches and three holes measuring up to 1 inch were noted in the east (far) bridge legs. The 2009 inspection report noted that the deck scuppers were cleaned since the last inspection; however, recommendations to clean the debris were still made and assigned a priority code of 5 (Routine).

In the 2011 inspection report, 3-inch holes in the west (near) legs, 2.5-inch holes in the east (far) legs, and knife edging and holes in the lower six transverse stiffeners were recorded. The 2013 report documented areas of severe corrosion in the west (near) legs with 100% section loss measuring 11 inches long by 11 inches high just above the bearing stiffeners, and again noted the knife edging with holes through the stiffeners and web of the southwest leg (B1R; see figure 28). The condition of the east (far) legs was reported as similar to that of the west (near) legs. The 2013 report further noted that all four legs had transverse stiffeners that were completely rusted through. A recommendation requiring immediate attention was made asking for "an analysis of the stability of the structure assuming that the cross braces are nonfunctional."[49] This analysis resulted in the bridge being load-rated and -posted to 26 tons (see section 1.12.3).

[49] This analysis was completed and is referred to in this report as the 2014 load rating analysis.

Figure 28. Corrosion of inside face of southwest leg (B1R). (Source: 2013 inspection report)

The 2014 interim inspection was the first inspection of the Fern Hollow Bridge that occurred 12 months (instead of 24 months) after the previous inspection. The introduction section of the 2014 interim inspection report noted that the inspection focused on the "frame legs (bents) of the three (3) span weathering steel rigid frame structure." This report highlighted widespread water and chloride that were leaching from the concrete deck onto the "fracture-critical frame legs and accelerating deterioration and section loss." The inspection did not recommend a structural review but did warn that if the deck and scupper drainage was not addressed, deterioration would accelerate.[50]

Yearly inspections occurred from 2014 to 2021, with two inspections in 2018. In the 2015 inspection report and later reports, 12-inch-by-12-inch holes in the leg web were reported along with thick lamellar corrosion (corrosion with a layered appearance, also known as exfoliation corrosion) and transverse stiffeners completely rusted through. The September 2017 inspection report identified three priority 1 findings including damaged "weight limit" and "ahead" signs (used to alert a driver of an upcoming limited load), loose junction box covers at the light poles on the sidewalks, and a nearly severed lower cross-frame bracing on Bent 1. The follow-up interim inspection in March 2018 noted that the signs had been repaired but needed to be readjusted and realigned. It also reported that the Bent 1 upper cross-bracing was severed and needed to be reattached, reinforced, or removed because it could

[50] Although some inspection reports referred to the legs as fracture-critical, the reports lacked detail to determine whether the legs were consistently considered to be FCMs and subjected to hands-on FCM inspections. However, the Fracture-Critical Identification Framing Plans never identified the legs as FCMs.

fall. These priority 1 findings required the City to perform a subsequent inspection 6 months later, in September 2018. The September 2018 inspection report noted that the alignment of the signage was still incorrect and the Bent 1 cross-bracing had continued to deteriorate and was in critical condition. The recommendation originally made in September 2017 to repair the cross-bracing was changed to priority 0 (Critical), and the signage recommendation remained coded as priority 1 (High Priority).

In December 2018, a resident of Pittsburgh took a photograph of a portion of the legs of the bridge and posted it to the social media site Twitter, tagging the City and stating, "I hope someone is keeping an eye on the underside of the Forbes Avenue Bridge over Frick Park? One of the big 'X' beams is rusted through entirely (and, yes, I see the cables, so it's probably not a crisis)."[51] In response, the 311 Response Center opened a tracking ticket 3 days later.[52] According to the resident, the steel cross-bracing was removed within a couple of weeks.[53]

The September 2019 inspection report noted that the Bent 1 cross-bracing had been removed and the misaligned signs had been corrected. The inspection also reported web portions of the legs exhibiting areas of thick lamellar corrosion with holes up to 12 inches long by 12 inches high just above the bearing stiffeners, as well as all four legs having transverse stiffeners that were completely rusted through. Recommendations were again made to repair and replace the stiffeners and holes and assigned a maintenance priority code of 2 (Priority). These recommendations to repair and replace the stiffeners and holes were made in every inspection report since 2007 (except for 2014, when no maintenance recommendations were made).

In September 2021, the legs were described as being in "poor condition." The legs exhibited holes up to 12 inches by 12 inches in the web above the bearing stiffeners as well as thick lamellar corrosion. The report also documented five stiffeners at each leg exhibiting 100% section loss (see figure 29). The inspectors assigned a priority code of 2 to the recommendation to "repair/replace stiffeners and weld repair plates over web holes on all four (4) legs."

In summary, the inspection reports between 2005 and 2021 documented heavy section loss on the bridge legs' transverse stiffeners, growing holes in the web above the bearing stiffeners, debris accumulation on the surface of the superstructure, and clogged drains. For 15 years or more, the inspection reports recommended a series of maintenance and repair recommendations including

[51] Twitter was rebranded as X in 2023.

[52] See Pittsburgh 311 Response Center Twitter post and City of Pittsburgh Service Request.

[53] See Pittsburgh Post-Gazette, "Pittsburgh man's 2018 photo shows rusted support under bridge that collapsed in Frick Park."

repairing/reinforcing the transverse stiffeners that had been rusted through; repairing the holes; and cleaning and painting the deteriorated parts of the superstructure, particularly the legs.[54]

Figure 29. Corrosion of inside face of southwest leg (B1R). (Source: 2021 inspection report)

Over the timeframe of 2005 to 2021, four recommendations were identified as priority 0 (Critical): two were related to load-posting signage, one was related to removal of a light pole with severe corrosion at its base, and the fourth (originally priority 1 [High Priority]) was related to removal of a cross-brace due to corrosion. Actions were taken in response to these recommendations.

Recommendations to address the corrosion—such as repairing the section loss on the web and transverse stiffeners on the legs, and painting areas of the legs—were consistently coded as priority 2 (Priority) but were not completed during the time period of 2007 to 2021. The only completed priority 2 item was re-tensioning of the retrofitted cable braces. Beginning in 2009, clearing of debris on the superstructure was considered a priority 5 (Routine) item to be completed in the next work cycle.

1.5.2.2 Superstructure Condition Ratings and Element Condition State Ratings

From 2005 through 2009, the Fern Hollow Bridge superstructure had a condition rating of 5 (Fair Condition). In 2011, the superstructure condition rating

[54] The application of paint or a rust-inhibitive coating is a common countermeasure used to mitigate corrosion. UWS bridges such as the Fern Hollow Bridge are initially constructed as uncoated and unpainted but may still benefit from these treatments.

dropped to 4 (Poor Condition) and remained at 4 through the 2021 inspection reports.[55]

Element data for the steel legs were collected during the 2019, 2020, and 2021 inspections. In the three inspection reports, all four bridge legs were assessed to be in CS4 (Severe) due to corrosion, which warrants a structural review (refer to table 5). No evidence was found that such a structural review was performed.

1.5.3 Inspection Oversight

1.5.3.1 National Bridge Inspection Program Compliance Review

In 2010, the FHWA developed a systematic, data-driven, and risk-based oversight process to monitor each state's compliance with the NBIS. The *National Bridge Inspection Program Compliance Review Manual* outlines the methods used to assess compliance with the NBIS (FHWA 2018).[56] The FHWA uses 23 metrics (directly related to the NBIS regulations in 23 *CFR* 650 Subpart C) to measure each state's compliance. Annually, each metric is assessed using various methods including reviewing bridge records and files, conducting field reviews on a sample of bridges, analyzing data from the NBI, interviewing state personnel, and using the reviewer's knowledge of the state bridge inspection program.[57] Each of the 23 metrics is assessed and classified as one of the following:

[55] According to NBI data, about 7% of bridges in the United States are considered to be in Poor Condition (condition rating 4 or worse; see Bridge Condition by Highway System 2023). Bridge condition is determined by taking the lowest of the NBI condition ratings for Item 58 (deck), item 59 (superstructure), item 60 (substructure), and item 62 (culvert). If the lowest rating is greater than or equal to 7, the bridge is classified as Good; if it is less than or equal to 4, the bridge is classified as Poor. The classification of a bridge as being in Poor Condition does not imply that the bridge is unsafe. Instead, the classification indicates the extent to which a bridge has deteriorated from its original condition when first built. A bridge with a classification of Poor might experience reduced performance in the form of lane closures or load limits. If a bridge inspection determines a bridge to be unsafe, it is closed; see Status of the Nation's Highways, Bridges, and Transit Conditions and Performance Report.

[56] The 2018 manual was in effect at the time of the collapse. The FHWA introduced a Performance Year 2024 Interim *National Bridge Inspection Program Compliance Review Manual* that incorporated revisions to the National Bridge Inspection Program in June 2022. See Federal Register: *National Bridge Inspection Program Compliance Review Manual*.

[57] The FHWA assesses the 23 metrics at a range of intensity levels based on risk and time since the last review. For example, at a minimum level the reviewer may use information from past assessments and their knowledge of the current practices, whereas an intermediate-level review would require reviews of bridge files, data, field reviews, and interviews. Intermediate reviews are required on metrics every 5 years. In-depth reviews are the most intensive and may require such actions as using a larger sample size for bridge reviews and conducting additional interviews.

- **Compliant (C)** – Adhering to the NBIS regulation.
- **Substantially Compliant (SC)** – Adhering to the NBIS regulation with minor deficiencies that do not adversely affect the overall effectiveness of the program and are isolated in nature.
- **Noncompliant (NC)** – Not adhering to the NBIS regulation, thus failing to meet one or more of the substantial compliance criteria for a metric. Identified deficiencies may adversely affect the overall effectiveness of the program.
- **Conditionally Compliant (CC)** – Taking corrective action in conformance with an FHWA-approved plan of corrective action in order to achieve compliance with the NBIS.

When issues of noncompliance are found, states are required to develop a plan of corrective action (PCA). If an acceptable PCA is not developed and implemented, the FHWA has the authority to enact penalties for noncompliance, including dedication of apportioned federal funding to correct the noncompliance.[58] Each year, the FHWA analyzes results from the state reviews to identify nationwide risks that may require closer review in future years.

The FHWA provided NBIS summary reports to the NTSB for performance year (PY) 18 through PY23 for PennDOT (see table 6).[59] Over this time period, PennDOT received ratings of Substantially Compliant or Compliant for most metrics in most years, and ratings of Conditionally Compliant for three metrics: metric 12, Inspection Procedures – Quality of Inspections (PY 22); metric 13, Inspection Procedures – Load Rating (PY22 and PY23); and metric 19, Inspection Procedures – Complex Bridges (PY23).[60]

In PY22, FHWA bridge reviews of inspections for metric 12 revealed that one of the 19 bridge inspections in its sample failed to note all deficiencies to support a rating, and four of the 19 bridges in the sample were missing photographs and/or sketches. The FHWA noted that the missing photographs were indicative of a failure to understand PennDOT's QA/QC procedures. Although the PY22 review focused on

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[58] See 23 *U.S.C.* 144(h)(5).

[59] The PY begins April 1 and ends March 31 of the following year to align with the program's requirement to make final compliance determinations by March 31 annually. For example, PY18 is from April 1, 2017, through March 31, 2018.

[60] Complex bridges are bridges that have component(s) or member(s) with advanced or unique structural members or operational characteristics, construction methods, and/or requiring specific inspection procedures. This includes mechanical and electrical elements of moveable spans and cable-related members of suspension and cable-stayed superstructures.

Pennsylvania Districts 1 (including Erie, Warren, Crawford, Mercer, Venago, and Forest Counties) and 12 (including Washington, Westmoreland, Fayette, and Greene Counties), through its interactions with PennDOT, the summary report indicated that the FHWA was aware of similar low-quality inspections being accepted by QC review personnel in other PennDOT districts. PennDOT's PCA in response to the FHWA's NBIS summary report findings included statewide training of QC review personnel on Pennsylvania's Publication 238 guidance related to requirements for quality inspections and inclusion of the requirements in bridge inspection refresher training.[61]

Metric 13 was also rated Conditionally Compliant in PY22, where the review indicated that seven of the 19 load ratings in the bridge files that were reviewed were not considered accurate, used invalid assumptions, or had substantial documentation deficiencies. PennDOT developed a PCA addressing these failures with a completion date of December 31, 2023; therefore, the Conditionally Compliant classification carried over into PY23.

Pennsylvania does not have a large number of complex bridges that are addressed in metric 19; only nine were identified for the metric population. Two of the complex bridges required routine inspections of electrical/mechanical components on a 24-month interval that were not performed in accordance with procedures. The FHWA is monitoring this metric to ensure that timely inspections are performed.

Table 6. Final summary of metrics for Pennsylvania for performance years 2018–2023.

Metric	Performance Year (PY)[a]					
	PY18	PY19	PY20	PY21	PY22	PY23
1. Bridge Inspection Organization	C	C	C	C	C	C
2. Qualifications of Personnel – Program Manager	C	C	C	C	C	C
3. Qualification of Personnel – Team Leaders	C	C	C	C	C	C
4. Qualifications of Personnel – Load Rating Engineer	C	C	C	C	C	C
5. Qualifications of Personnel – Underwater Inspection Diver	C	SC	C	C	C	C
6. Routine Inspection Frequency – Lower Risk Bridge	C	C	C	C	C	C
7. Routine Inspection Frequency – Higher Risk Bridge	C	C	C	C	C	C

[61] A PCA is a documented agreement, prepared and submitted by the state department of transportation and approved by the FHWA Division, containing specific actions and timelines to correct noncompliance issues related to NBIS metrics to achieve compliance.

Metric	Performance Year (PY)[a]					
	PY18	PY19	PY20	PY21	PY22	PY23
8. Underwater Inspection Frequency – Lower Risk Bridge	C	C	C	C	C	C
9. Underwater Inspection Frequency – Higher Risk Bridge	C	C	C	C	C	C
10. Inspection Frequency – Fracture-Critical Member	SC	C	C	C	C	C
11. Inspection Frequency – Frequency Criteria	C	C	C	C	C	C
12. Inspection Procedures – Quality of Inspections	C	SC	SC	SC	CC	C
13. Inspection Procedures – Load Rating	C	C	C	C	CC	CC
14. Inspection Procedures – Post or Restrict	C	C	C	C	C	C
15. Inspection Procedures – Bridge Files	C	C	C	C	C	C
16. Inspection Procedures – Fracture-Critical Members	C	C	SC	SC	SC	SC
17. Inspection Procedures – Underwater	C	C	C	C	C	C
18. Inspection Procedures – Scour-Critical Bridges	C	SC	SC	SC	SC	SC
19. Inspection procedures – Complex Bridges	C	C	C	C	C	CC
20. Inspection Procedures – Quality Control/Quality Assurance	C	C	C	C	C	C
21. Inspection Procedures – Critical Findings	SC	C	C	C	C	C
22. Inventory – Prepare and Maintain	C	C	C	C	C	C
23. Inventory – Timely Updating of Data	SC	SC	SC	SC	C	C

C = Compliant
SC = Substantially Compliant
CC = Conditionally Compliant
[a] Ratings are as of March 31 of the PY. For example, PY18 ratings are for the period of April 1, 2017, through March 31, 2018.

PennDOT has received ratings of Substantially Compliant or Compliant for the 23 metrics. Details are provided in section 2.5.3.

1.5.3.2 State Responsibilities for Quality Control and Quality Assurance

States are required to ensure that systematic QC and QA procedures are used to maintain a high degree of accuracy and consistency in the bridge inspection program.[62] *QC* refers to procedures that are intended to maintain the quality of a bridge inspection, bridge data, scour evaluation, and load rating at or above a specified level. *QA* refers to the use of sampling and other measures to assure the adequacy of QC procedures and verify or measure the quality level of the entire

[62] See 23 *CFR* 650.31(p). The AASHTO *MBE* (AASHTO 2018) is incorporated by reference.

bridge inspection and load rating program. The FHWA has implemented a framework for the states to develop QC and QA programs that meet the specific requirements of the NBIS.

PennDOT's Publication 238 details Pennsylvania's QC program and provides guidance for ensuring that staff are qualified, field inspections are reviewed and required and important information is captured, and maintenance and repair recommendations with priority 0 or 1 designations are immediately addressed (PennDOT 2022a). The PennDOT QA program, described in Publication 240, consists of independently reinspecting a selection of NBIS bridges in each district as well as some that are owned by other entities (PennDOT 2020). According to the assistant chief bridge engineer for PennDOT, about 220 of the estimated 30,000–32,000 bridges in Pennsylvania (about 20 per district) are reinspected by PennDOT as part of the QA program each year. A third-party, unbiased team of engineers who did not perform the inspection under review is used for the QA process. The results of the QA reinspection reports are compared with the results of previous inspection reports. In the last few years, there has been an emphasis on comparing aspects of the inspections—such as methods used to access the bridge and documentation and comments about the bridge and load ratings—in addition to data points such as condition ratings and priority codings. The QA process concludes with a meeting with the district to discuss the results.

1.6 Fern Hollow Bridge Maintenance

Records related to the maintenance and rehabilitation of the Fern Hollow Bridge were obtained from the City and City contractors. The records included construction plans, records pertaining to maintenance and repaving of the roadway, work orders for bridge-related signage, rehabilitation plans for the Fern Hollow Bridge, and a 2019 contract for structural rehabilitation and renovation/preventative maintenance work to cover bridges throughout the city.[63]

1.6.1 Roadway Repaving and Pavement Maintenance

The thickness of the bridge's asphalt wearing surface is important because the weight of the asphalt must be accounted for in the bridge's load rating. The Fern Hollow Bridge was designed in 1973 with a 3-inch-thick asphalt wearing surface. The City provided documentation on several milling and replacement projects starting in 1983. The documentation did not specify whether the work was performed on the bridge structure or only on the adjacent roadway. Except for the 2017 project list, which indicated that 0 to 3 inches of asphalt were milled and 0 to 4 inches were

[63] These records and documents are available in the public docket for this investigation.

replaced on the bridge, the records did not provide enough information to determine how much asphalt was removed or how much was restored through paving during each resurfacing project. An interview with officials from a City contractor stated that normal practice was to replace the depth of asphalt that was milled away.[64] Additionally, no evidence was found confirming the thickness of the wearing surface when the bridge was built. Table 7 provides a summary of the documented pavement maintenance activities.

Table 7. Summary of documented pavement activities on Forbes Avenue.

Date	Description of Work Performed	Documented Location
7/19/1983	Asphalt surface milled and replaced	Forbes Ave., between S. Braddock Ave. and bridge (toward S. Dallas Ave.)
6/27/2000	Asphalt surface milled and replaced	Forbes Ave., between "Bridge at Frick Park" and 0.2 miles west
7/18/2005	Asphalt surface milled and replaced (in patches)	Between S. Braddock Ave. and S. Dallas Ave.
5/6/2009	Asphalt surface milled and replaced	Between S. Braddock Ave. and S. Dallas Ave.
4/30/2016	Crack sealing	Forbes Ave.
7/12/2017	Asphalt surface milled (0–3 inches) and replaced (0–4 inches)	Forbes Ave., S. Dallas Ave. to S. Braddock Ave.
10/25/2017	Asphalt surface milled (0–3 inches)	Forbes Ave. Bridge
11/21/2017	Asphalt surface replaced (0–4 inches)	Forbes Ave. Bridge

1.6.2 Bridge-Related Signage

Two work orders related to signage placement along Forbes Avenue near the Fern Hollow Bridge are summarized in table 8. One was related to the installation of the 35-mph speed limit sign along Forbes Avenue. The other was related to the installation and update of weight limit signs placed in advance of the bridge that read "Weight Limit 26 Tons."

[64] The transcript of this interview is available in the public docket for this investigation.

Table 8. Summary of work orders related to signage along Forbes Avenue.

Work Order No.	Dates	Description of Work Performed
1550	10/11/1945 - 11/20/2019	Installation of 35-mph speed limit signage along Forbes Avenue
65197	5/9/2014 - 10/1/2015	Installation of load limit-related signage in advance of bridge

1.6.3 2009 Rehabilitation Plan

In September 2007, the City entered a contract for engineering services related to the rehabilitation of the Fern Hollow Bridge to complete the following:

1. Replace the downspouts and brackets.
2. Repair a crack in the knee brace supporting floor beam #6 at North Girder.[65]
3. Replace the cross-bracing of the frame legs from mid-height to the shoes for both the east and west legs.
4. Apply a rust-inhibiting coating on frame legs and lower bracing members.
5. Review the shop drawings for the downspouting and the cross-bracing.

Records from the City indicated that the work to replace the downspouts and repair the crack in the knee brace was completed in April 2009. However, the engineer of record for the rehabilitation project stated that the plan to replace the cross-bracing was changed to the installation of structural steel cable bracing as a temporary measure to brace the bridge against wind loads until the rigid cross-bracing could be replaced. Additionally, the application of the rust-inhibiting coating was delayed at the request of the City's Department of Public Works (the precursor to DOMI) citing weather concerns. A note on the "as-built" plans for the repairs indicated that the bottom halves of the legs were not cleaned or painted with the rust-inhibiting coating following the completion of the work. There were no City records indicating either that the coating was applied at a later date or that any payment was made for the application of the coating. Postcollapse, investigators did not find any evidence that a rust-inhibiting coating was ever applied to the legs.

[65] A *knee brace* is an angled brace, in this case between the floor beam and girder.

1.6.4 Other Contracts in Place at Time of Collapse

1.6.4.1 Stormwater Drainage

At the time of the collapse, the City did not have a preventative maintenance schedule to clean out the stormwater drainage system for the Fern Hollow Bridge. To clean stormwater drainage, DOMI would have had to hire a contractor because it did not have in-house resources for this work. The City stated that it did not request the services of a contractor to clean the drainage system from January 7, 2019, through January 28, 2022, nor could it produce any individual invoices from before January 7, 2019. The 2009 inspection report noted that deck scuppers, part of the bridge drainage system, had been cleaned since the 2007 inspection. None of the other inspection reports included such a statement.

1.6.4.2 Structural Rehabilitation and Renovation

The City established a contract for structural rehabilitation and renovation of its bridges for the period of June 1, 2019, to May 31, 2021, with an extension to May 31, 2022. The scope of the contract included "bridge preventative maintenance, bridge maintenance and repair at various locations throughout the City."[66] The City did not provide any documentation to the NTSB indicating that any services or repair items were performed on the Fern Hollow Bridge during the contract period. City records showed that maintenance work was completed on other Pittsburgh bridges and that this work was undertaken due to urgent structural issues noted in inspection reports.

1.7 Postcollapse Corrosion Mapping

Postcollapse, the NTSB and FHWA recovered and examined all four legs from the collapse site. Extensive corrosion was visible on each of the legs, especially on their lower portions. The lower portions of all four legs were manually cleaned of debris and loose dirt, and the pieces were pressure-washed with water. Due to corrosion deposits in numerous locations and the need to reveal the remaining metal, the leg pieces were further cleaned with an immersion bath.[67] Three-dimensional (3D) laser scanning was performed to document the entirety of the lower legs and to enable measurement of the thickness of their remaining material. For each figure in this section, the top image shows the bridge leg postcollapse, and the bottom image shows its corresponding 3D image. The 3D images were created with a lower-bound threshold to display areas containing more than 0% remaining section; thus, the white areas in the 3D images indicate a hole or complete (100%)

[66] This contract is available in the public docket for this investigation.

[67] For more information, see the *Materials Laboratory Factual Report 23-009* in the public docket for this investigation.

section loss, and the colored portions represent areas where material remained. The blue coloring corresponds to regions where there was no section loss (or 100% of the section remained). For each figure, the thickness of the element according to the design plan is provided in the scale. For example, in figure 32 the thickness of the web according to the design plan was 0.5 inches; the blue coloring indicates areas where the plate's thickness measured 0.5 inches (or 100% of its thickness according to the design plan), and the yellow coloring indicates areas where the web's thickness measured 0.125 inches (or about 25% of its thickness according to the design plan). The northwest leg (B1L) is shown in figure 30, the northeast leg (B2L) is shown in figure 31, the southeast leg (B2R) is shown in figures 32 and 33, and the southwest leg (B1R) is shown in figures 34 and 35.[68]

[68] Note that for figures 30 to 35, the angle shown in the photograph may differ slightly from the angle shown in the 3D laser scan image.

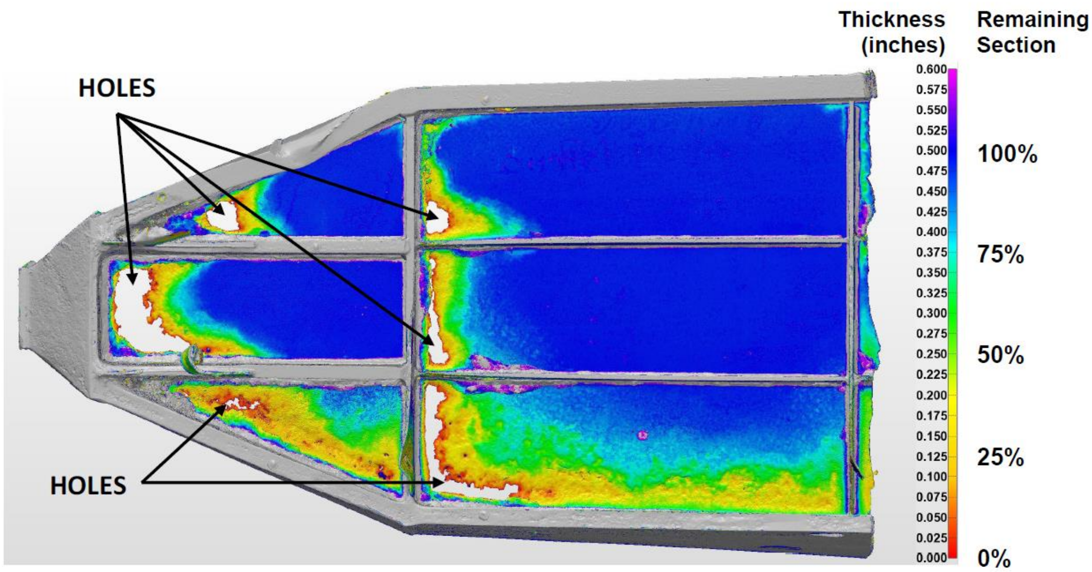


Figure 30. Photograph and 3D laser scan image showing remaining section of inward side of northwest leg (B1L). According to the design plan, the nominal thickness of the leg web was 0.5 inches.

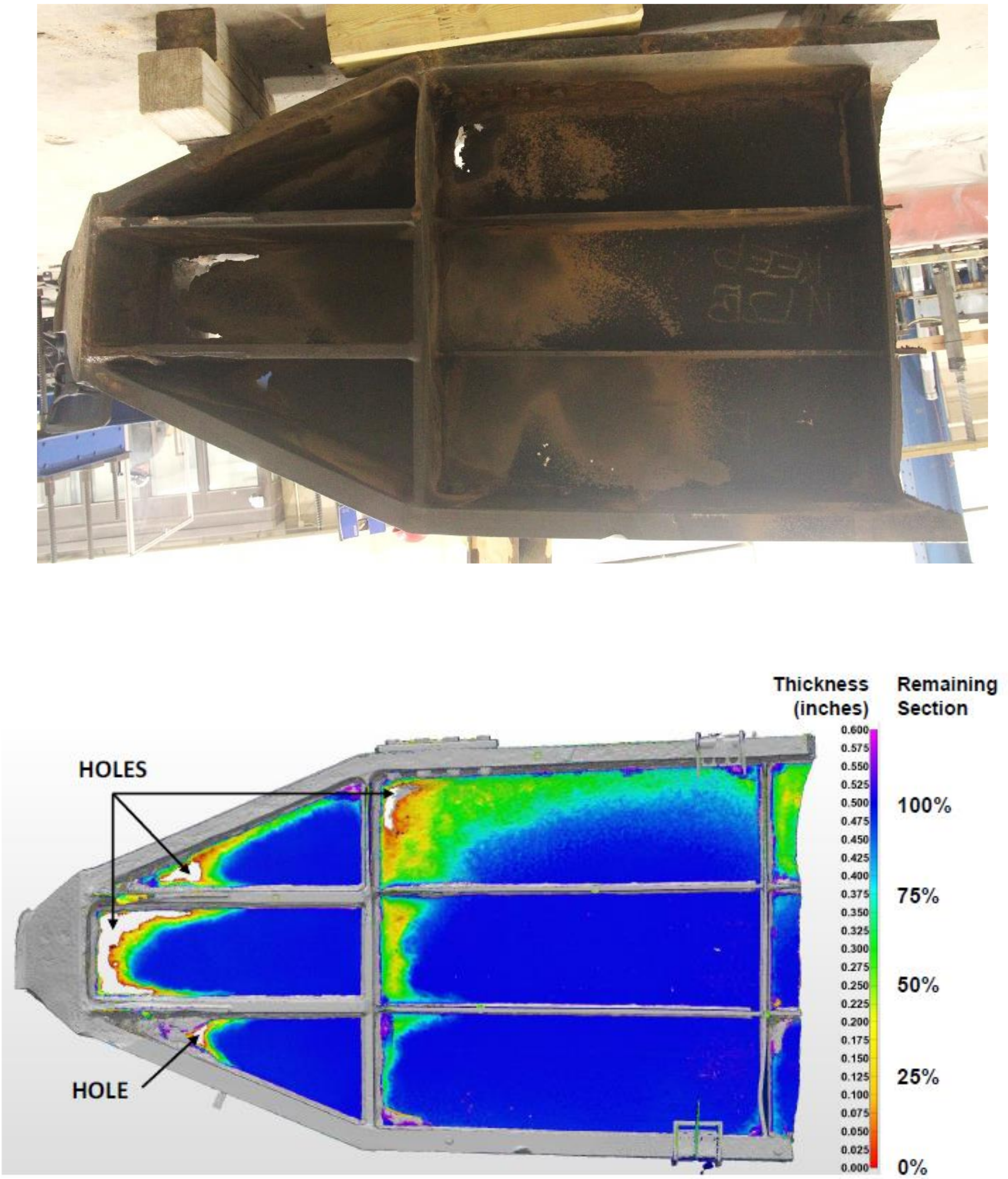


Figure 31. Photograph and 3D laser scan image showing remaining section of inward side of northeast leg (B2L). According to the design plan, the nominal thickness of the leg web was 0.5 inches.

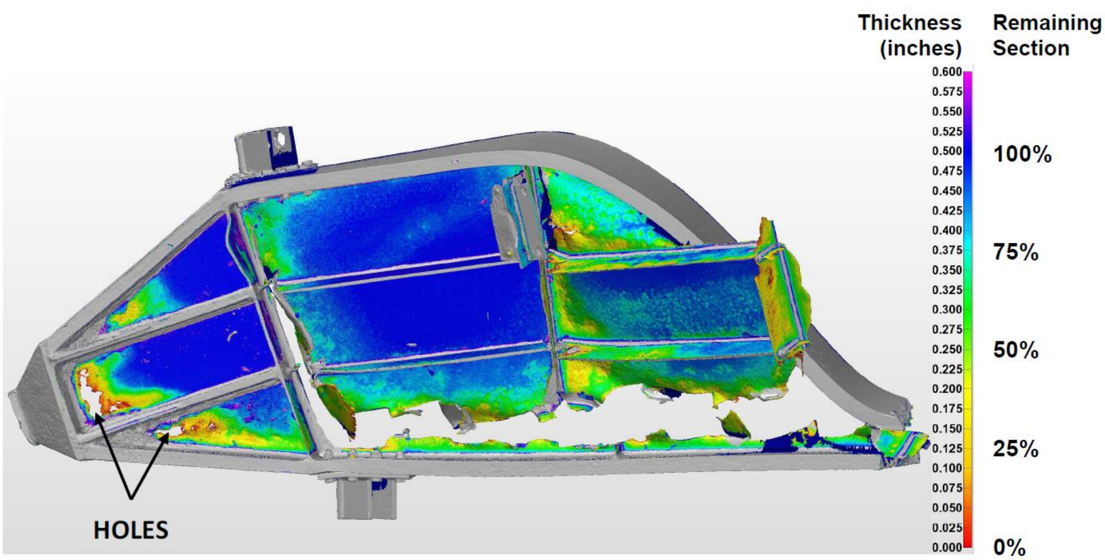
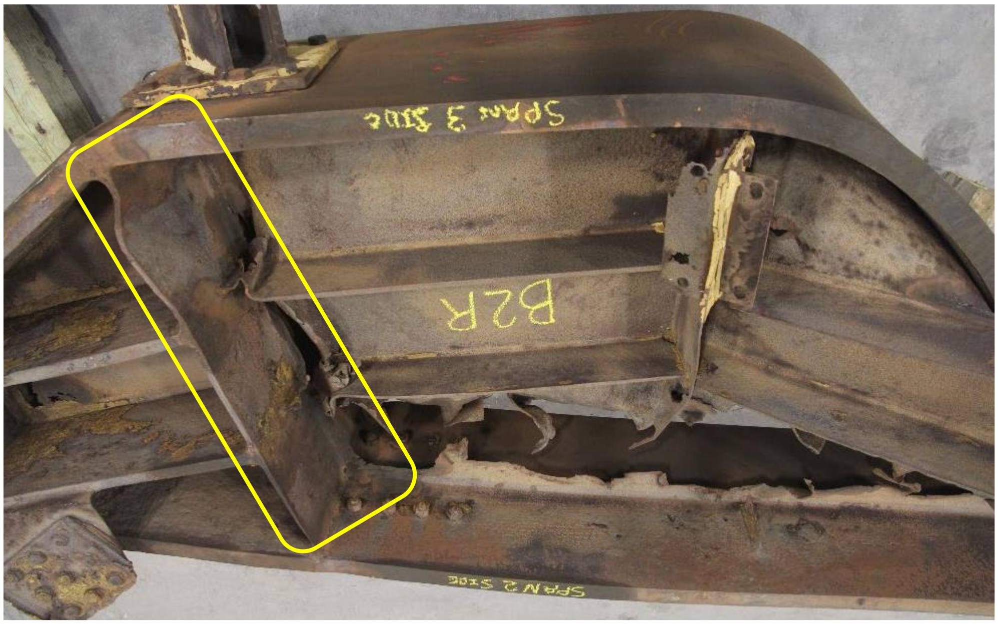


Figure 32. Photograph and 3D laser scan image showing remaining section of inward side of southeast leg (B2R). According to the design plan, the nominal thickness of the leg web was 0.5 inches.



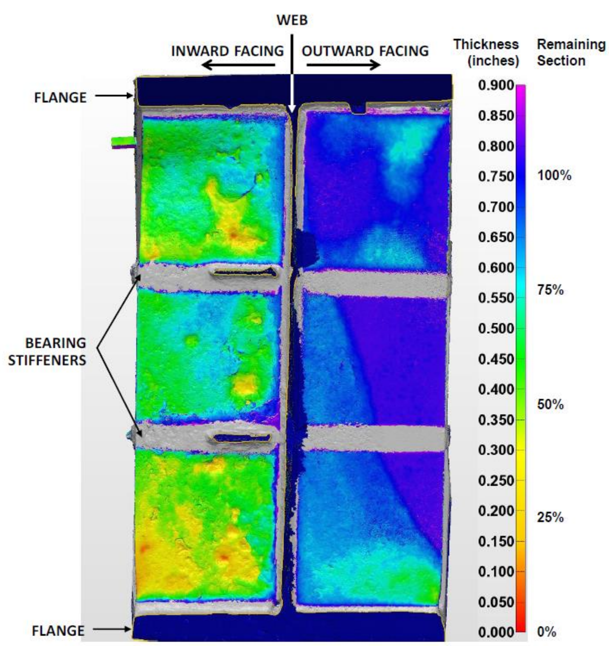


Figure 33. Photograph and 3D laser scan image showing remaining section of southeast leg (B2R) transverse tie plate (outlined in yellow in the photograph). According to the design plan, the nominal thickness of the tie plate was 0.75 inches. The top photograph shows only the inward side of the transverse tie plate. The bottom, scanned image shows both the inward and outward sides of the tie plate.

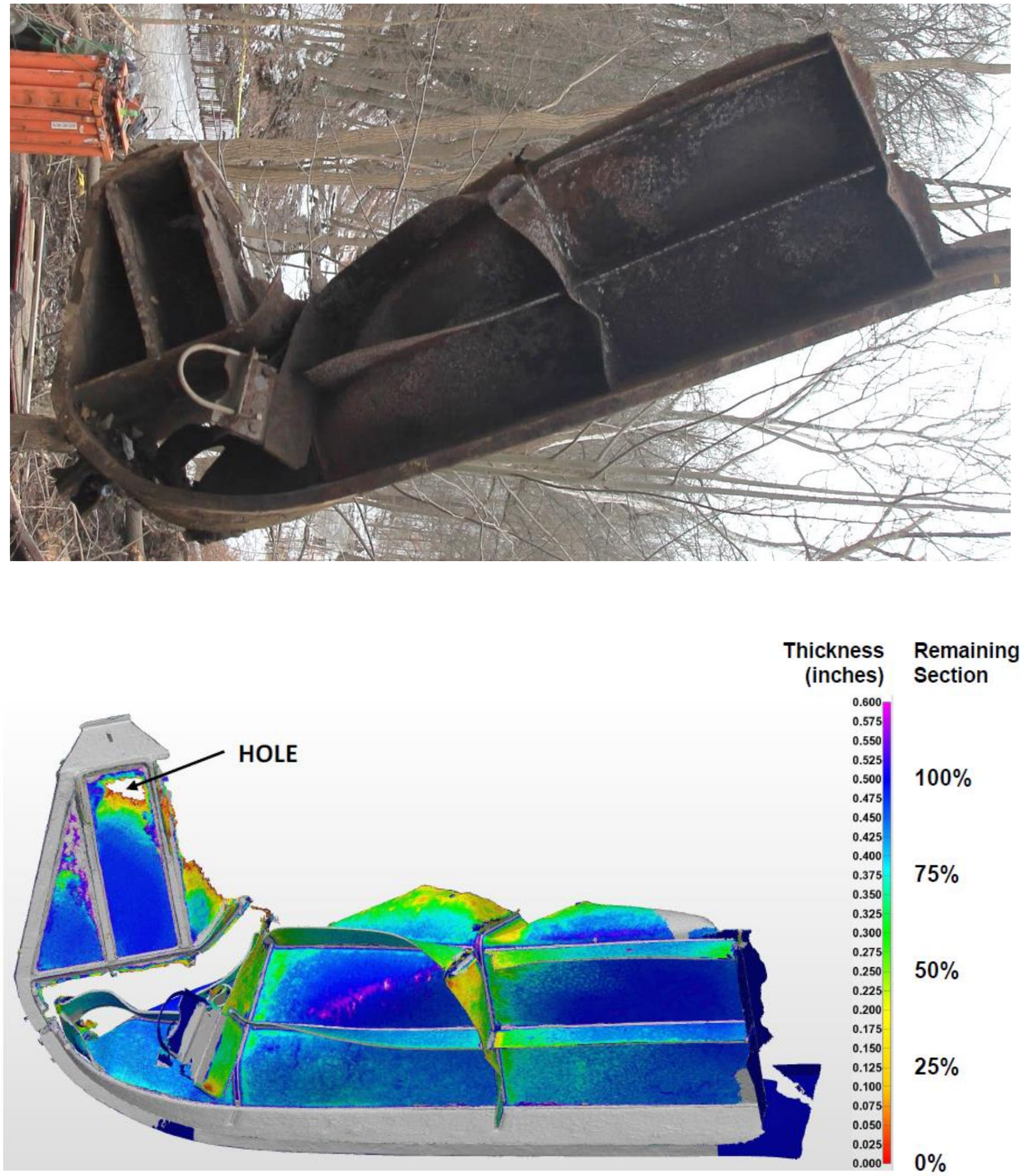


Figure 34. Photograph and 3D laser scan image showing remaining section of inward side of southwest bridge leg (B1R). According to the design plan, the nominal thickness of the leg web was 0.5 inches.

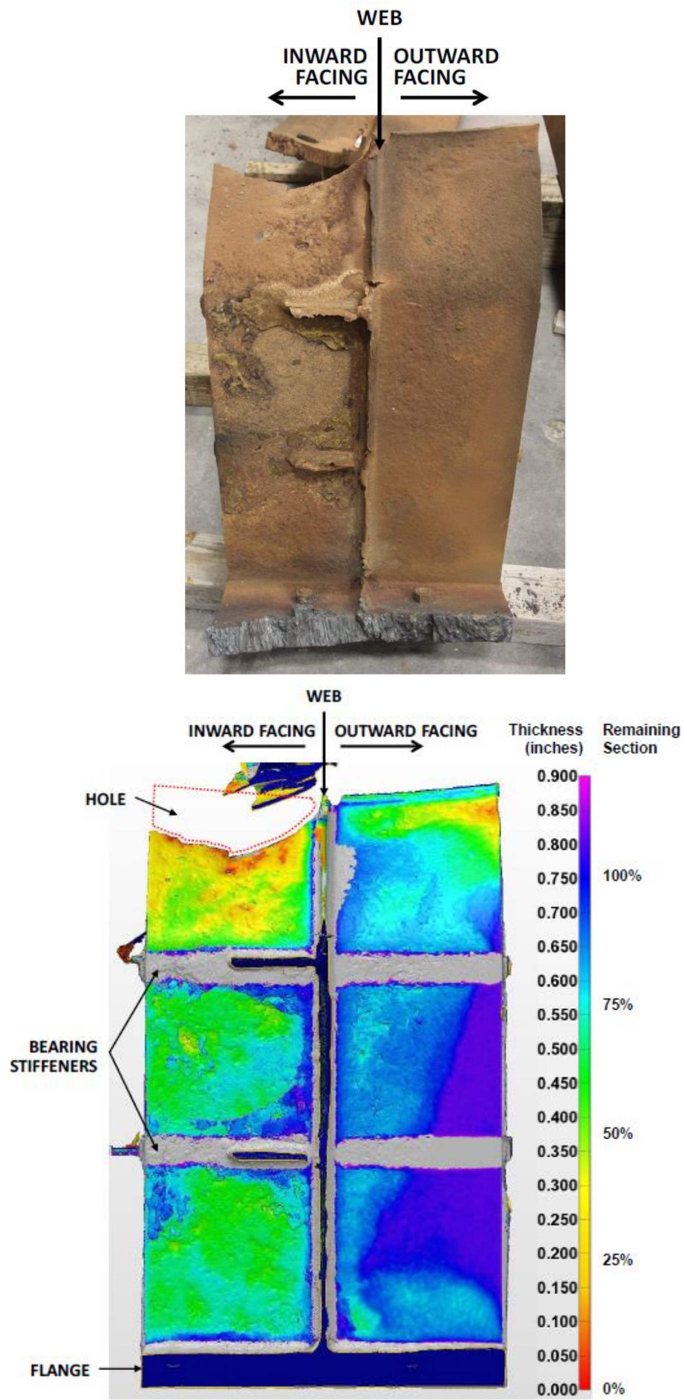


Figure 35. Photograph and 3D laser scan image showing remaining section of southwest bridge leg (B1R) transverse tie plate. According to the design plan, the nominal thickness of the tie plate was 0.75 inches.

1.8 Materials Testing

1.8.1 Uncoated Weathering Steel

The design plans for the K-frame Fern Hollow Bridge called for the use of ASTM A588 steel. This steel belongs to a group of steels commonly referred to as uncoated weathering steel, or UWS, which have a carbon content of less than 0.2% by weight to which a small percentage of alloying elements are added.

UWS has been used in building bridges since the mid-1960s. In 1984, there were an estimated 1,800 bridges built of UWS in the United States (Albrecht and Naeemi 1984). By 2014, the estimate grew to more than 10,000 bridges built in the United States using UWS (McConnell and others 2014). Current estimates using FHWA data indicate that of the more than 10,000 bridges built of UWS, 32 are frame bridges (such as K-frame or delta frame).[69] In Pennsylvania, there are 7 bridges with frame designs that are constructed of UWS.

One of the characteristics of UWS is the ability to form a dense and adherent rust layer, called a patina, that resists further corrosion of the steel. The protective patina is developed during alternating wet and dry cycles. The dry periods are critical to the steel's ability to form a patina.

The benefits of UWS include its cost-effective performance, its appearance in natural environments, and its lower impact on the environment because it does not require painting. Although the initial material cost of UWS is slightly higher, the elimination of the need for painting reduces long-term maintenance costs. However, certain weather and climate conditions can lower its durability and resistance to corrosion. For example, the presence of ponding water and debris buildup can trap water and debris on and around the bridge structure, prevent the steel from drying, and preclude the formation of the protective patina, which in turn enables corrosion and deterioration to occur and reduces the safety and service life of the UWS. Additionally, these buildups can contain residual roadway salts that further contribute to corrosion. As described in an FHWA Technical Advisory, adequate drainage and maintenance is required to allow the UWS material to cycle between periods of wet and dry and form a protective patina (FHWA 1989).

[69] (a) For FHWA bridge data, see FHWA LTBP [Long-Term Bridge Performance] InfoBridge. (b) *Delta frame* is a superstructure design type with two or more girders running the length of the bridge and two angled legs connected to each girder, giving the appearance of a downward pointing triangle.

1.8.2 Material Testing Results

The bridge design plans specified that the bridge legs were to be constructed from plates of ASTM A588 steel. Mill test reports listed the tensile strength, Charpy v-notch impact strength, and chemical composition for each plate of steel delivered by the mills at the time of construction.[70] Multiple bridge components were evaluated to determine whether the materials used when constructing the bridge met the ASTM International and mill test report specifications. The testing was conducted with NTSB oversight at the FHWA Turner-Fairbank Highway Research Center.

Most of the plates met tensile strength requirements, and those that did not were at most 4% below minimum standards. All of the plates with nonconforming strength were located within the girders.

All of the tested Charpy v-notch impact specimens met energy absorption requirements. Several of the tested steel plates did not conform to the specified chemical composition. The NTSB reviewed the results for effects on steel corrosion resistance and determined that the nonconformant plates could have formed a protective patina under appropriate conditions.

In addition to the testing performed to evaluate specified material properties, metallographic examination of cross-sections through the welds at the top of each leg and at the end plate of each leg was conducted because the welds on the Fern Hollow Bridge legs were different from the welds called for in the design plan.[71] Most of the welds at the tops of the legs showed a lack of fusion with the sidewalls.[72] Cracks observed in the welds at the tops of two of the legs either contained pack rust—which would have developed over time with exposure to the elements and in advance of the collapse—or else appeared fresh, suggesting that they occurred during the collapse.[73] None of the cracks displayed characteristics consistent with fatigue fracture.

[70] The Charpy v-notch impact test measures the energy absorbed by a specimen during fracture.

[71] No fabricator plans were located during the investigation; thus, modifications to weld specifications could not be identified for comparison.

[72] *Sidewall* refers to the joint interface between a weld bead and a structural element. If a weld shows lack of fusion to a sidewall, this indicates that the weld did not sufficiently penetrate the base metal of the structural element.

[73] *Pack rust* is a term used to describe localized corrosion; in bridges, pack rust forms between connected structural elements when corrosion of contacting surfaces occurs and rust "packs" between them. Pack rust may also be referred to as crevice corrosion.

1.9 Finite Element Model

PennDOT contracted to have a finite element (FE) model developed to evaluate the as-built design of the bridge and to examine the collapse sequence (Modjeski and Masters 2023).[74] The NTSB expanded on the developed FE model to further examine the contribution of the extensive section loss in specific leg components, as well as the additional weight of the wearing surface thickness as documented postcollapse, to the modeled bridge's ability to withstand applied loads.

The results revealed that, as designed and with no section loss due to corrosion, the modeled bridge had sufficient capacity to carry the vehicles on the bridge at the time of the collapse. In addition, the modeled bridge with the wearing surface thickness doubled also had sufficient capacity to carry the vehicles on the bridge.

The results of the FE model incorporating material properties for the steel used in the bridge, detailed section loss, the double wearing surface thickness, and the vehicle weights present on the bridge immediately before the collapse were consistent with the postcollapse physical evidence in the field. The combination of section loss and the added weight of the wearing surface reduced the capacity of the modeled bridge such that it was unable to carry the posted load limit of 26 tons.

Importantly, the results indicated that the extensive section loss played a much larger part in reducing the modeled bridge's ability to carry loads than the additional weight of the wearing surface thickness. Further, the FE model indicated that a failure of the base of the southwest leg (B1R) would lead to the modeled bridge's collapse. Specifically, the section loss in the transverse tie plate at the top of the B1R shoe resulted in the failure of this component, leading to separation of the flange and transverse tie plate, which subsequently caused the flange to peel away from the web. Although the welds at this location on the actual bridge did not meet design requirements, the FE model revealed that this effect was minor and resulted in only a small reduction in the load capacity of the modeled bridge.

[74] A *finite element model* is a computer model describing a virtual assembly of simplified structural elements used to approximate a complex structure. The behavior of the complex structure is then calculated by combining the actions of the interconnected simpler elements. FE modeling uses calculations and simulations to understand how an object might behave under various loading conditions. PennDOT contracted with Modjeski and Masters to analyze the Fern Hollow Bridge collapse using FE modeling.

1.10 Limited Examinations of Additional Bridges

The NTSB and FHWA conducted limited examinations of 10 steel-frame bridges similar to the Fern Hollow Bridge, some of which were constructed using UWS, within Pennsylvania's bridge inventory. The examinations found built-up debris in and around bridge legs, improper drainage, and associated corrosion, although not as severe as identified on the Fern Hollow Bridge. Additionally, the FCM framing plan for one of the examined bridges, the Murray Avenue Bridge, was found to be incorrect because its legs were not identified as FCMs. Table 9 lists the examined bridges.

Table 9. Additional Pennsylvania bridges examined by the NTSB and FHWA.

Name of Bridge	County Name	Year Built	Type of Bridge	Bridge with FCMs
Murray Avenue	Allegheny	1978	Painted steel K-frame	Yes
East Street	Allegheny	1986	Painted steel K-frame	No
Shenango Road	Beaver	1976	UWS K-frame	Yes
South Oakland	Mercer	2006	UWS K-frame	No
Hecla Road (SR 2007)	Westmoreland	1939 [a]	Painted steel K-frame	No
Sample Bridge Road	Cumberland	1973	UWS delta frame	No
Slate Hill Road	Cumberland	1973 [b]	UWS K-frame	No
Fahy (SR 3011)	Northampton	1972 [c]	UWS K-frame	Yes
Valley Forge Road	Montgomery	1972	Painted steel frame	No
McCallum Street	Philadelphia	1985	UWS delta frame	Yes

[a] Reconstructed in 1988 over Pennsylvania Turnpike (I-76).
[b] Reconstructed in 2012.
[c] Reconstructed in 2017.

The NTSB and FHWA also visited the Chapel Road Bridge in West Virgina, a similar K-frame UWS bridge designed by the same engineer as the Fern Hollow Bridge and built in 1972. According to a West Virginia Department of Transportation bridge inspector, the legs of this bridge are considered to be FCMs and are treated as such during inspections. The inspector stated that the bridge was in fair condition. The drains appeared to have been recently cleaned. The steel in corrosion-prone areas—such as the ends of the girders, field-splice locations, and bottom portions of the legs—had been coated with a rust-inhibiting coating in 2020 as a preventative measure.

1.11 Interviews

1.11.1 Interview with Fatigue and Fracture Bridge Inspection Plan Engineer

The NTSB and FHWA interviewed the engineer who developed the Fatigue and Fracture Bridge Inspection Plan for the Fern Hollow Bridge and who also served as a team leader. He noted that he earned an engineering technology degree in 1981 and had “at least 35” years of experience inspecting bridges, including “probably 30” bridges with FCMs.

When asked why the superstructure condition of the bridge was never rated below a 4 even though the bridge legs were given a rating of Poor to Critical, he responded that “they [inspectors] were always told not to base the overall rating on one condition.” He stated that “the number one problem was the clog[ged] scuppers and downspouts on almost all their bridges” and that he “told them [the City] to clean the thing, clean the thing. Nothing was done.” In response to a question about why a load rating was not recommended given a change in condition, he stated, “probably because they [inspectors] felt like it wasn’t enough of a change in condition to affect it.” He noted that the QC process involved an inspector writing and signing off on the inspection report; another inspector reviewing and signing off on it; and a third, independent reviewer (someone who was not present at the inspection) completing an additional review.

The engineer indicated that the bridge legs were not identified as FCMs because “they considered them to be in compression only when they did the analysis, and a pressure [fracture]-critical member isn’t a compression member. It’s a tension member.“

1.11.2 Interview with Assistant Chief Bridge Engineer

According to the assistant chief bridge engineer for PennDOT, there are about 22,000 bridges in Pennsylvania that are state- or locally owned and subject to the NBIS. The assistant chief bridge engineer noted that, for an inspection of a City-owned bridge (such as the Fern Hollow Bridge), the City can choose to use a contractor through PennDOT. After the inspection is completed, the inspector sends the report and any letters with priority recommendations to the local owner and to PennDOT. PennDOT reviews the report at the district level. He indicated that PennDOT tracks the maintenance items with priority codes 0 and 1, and stated that, “once it goes in as a 2, it’s going to fall off of any type of report that we have, which really just focuses on 0s and 1s.”

Regarding NSTM plans (also referred to as Fatigue and Fracture Bridge Inspection Plans), the assistant chief bridge engineer indicated that PennDOT is taking steps to make them more consistent. He described the plans as a "one-stop shop."

1.12 Federal Highway Administration Report on Fern Hollow Bridge Collapse Investigation

In support of this investigation, the FHWA reviewed the Fern Hollow Bridge inspection reports between 2005 and 2021, including the Fracture-Critical Identification Framing Plans and Fatigue and Fracture Bridge Inspection Plans as well as the previous load rating calculations for the bridge.

1.12.1 General Inspection Findings

The FHWA reviewed the inspection reports as well as bridge inventory information for the Fern Hollow Bridge. The following is a list of major findings from the FHWA review:

- The routine and FCM inspections were performed at intervals set in accordance with the NBIS. Interim inspections were performed in accordance with PennDOT requirements.

- Although section loss was documented, the inspection reports did not document the remaining material thicknesses adjacent to the corrosion holes or in areas where section loss did not result in holes. The size and shape of holes and the amount of material remaining in critical bridge members are needed for load rating calculations to accurately assess how much weight the bridge can safely carry in its reported condition.

- The inspection reports contained photographs showing corrosion on the legs, but most reports did not include evidence of cleaning the steel to obtain accurate measurements of remaining section. The *MBE* states that rust scale (or corrosion) needs to be "removed down to base metal" to obtain these measurements (AASHTO 2018).

- Based on a review of the inspection information, the *Coding Guide* (FHWA 1995), and the *BIRM* (FHWA 2002), the superstructure coding rating should have been coded as a 3 (Serious Condition) or even a 2 (Critical Condition), instead of a 4 (Poor Condition) or 5 (Fair Condition).

- The bridge element data collected in September 2019, 2020, and 2021 for the bridge legs appropriately assessed the legs as CS4 (Severe), which warrants a structural review. There was no evidence that a structural review was performed.

- Repairs to the bridge legs to address the significant section loss to the web and the transverse stiffeners were not assigned a high priority on the PennDOT scale by inspectors and were never performed.

1.12.2 Fracture-Critical Member Findings

As part of the inspection review, the FHWA evaluated whether an FCM inspection was required and identified which structures of the bridge were fracture-critical. Based on the review of the Fern Hollow Bridge inspection reports and its structural analysis, the FHWA determined the following:

- The Fern Hollow Bridge was supported by only two parallel rigid frame lines; therefore, the frames lacked load path redundancy.

- The rigid frame girders were partially in tension; therefore, the frame girders were FCMs. The rigid frame girders were appropriately identified as FCMs in the FCM plan.

- The top two-thirds of the bridge legs would experience tension under design loads and were FCMs.

- The transverse tie plates at the top of each shoe on each leg were in tension due to the transition in the angle of the flange at this location.

- Portions of the non—load-path-redundant steel bridge legs were in tension; therefore, the bridge legs, including the transverse tie plates, should have been labeled as FCMs in the Fracture-Critical Identification Framing Plan and subject to hands-on inspection.

According to the FHWA, the degree to which the bridge legs were considered FCMs and subjected to hands-on inspection was not consistent across the inspection reports:

- From 2005 through 2015, the inspection reports included a narrative section on “fracture critical members and intersecting welds.” Within this narrative were notes on the girders, floor beams, and bridge legs.

- In 2011, the Fracture-Critical Identification Framing Plan included in the inspection reports identified the floor beams and portions of the girders as FCMs but did not identify the bridge legs as FCMs.

- The 2016 Fatigue and Fracture Bridge Inspection Plan identified the girders and floor beams as FCMs. The diagram included in the plan was dated 2015 and included a few additional notes on the floor beams and girders but was otherwise identical to the diagram from the 2011 plan, including not identifying the bridge legs as FCMs.

- In 2017, the FCM inspection results for the girders and floor beams were included in Form F: Fracture Critical. There was not enough information to determine whether these results included the bridge legs in addition to the girders, nor was there enough information to determine the manner in which the FCMs were inspected.

- FCM inspections that did include the bridge legs only focused on the welds connecting the longitudinal stiffeners to the legs. There was no evidence that a hands-on inspection of the transverse tie plate was conducted.

Additional observations were made by the FHWA regarding the FCM inspection plans, procedures, and results. Although the 2016 plan described ways to access the FCMs for the hands-on inspection, it failed to provide details on the inspection methods to be used on the FCMs, nor did it describe the use of non-destructive evaluation (NDE) methods such as those needed to obtain accurate measurements of cracks. The only time the use of an NDE method was documented in the reviewed inspection reports was in the 2005 report.[75] Further, the FHWA noted that the inspection reports from 2017 forward contained insufficient information about the method of inspection and whether the inspection was completed according to FCM procedures. The FHWA also indicated that the FCM inspections focused on fatigue-induced cracking and did not address other deterioration modes, such as section loss due to corrosion, that could lead to member failure.

1.12.3 Load Rating Evaluation and Findings

Load rating refers to the determination of the maximum vehicular load that a bridge can safely carry in its current condition, with consideration made for documented deterioration. Load ratings are determined by analytical methods based on information from bridge plans and supplemented by information from field inspections, testing, or both (AASHTO 2018). The FHWA evaluated the previous load rating analyses for the Fern Hollow Bridge that were conducted in 2000, 2003, and 2014, and independently calculated the load ratings to assess the results. Among other findings, the FHWA determined that the 2000 and 2003 load ratings provided a

[75] The 2005 inspection report documented dye-penetrant testing on floor beam weld cracks. Although the cracks were not mitigated, future inspection reports did not document NDE methods to track them.

valid representation of the structural condition and capacity of the floor beams and girders. However, neither the 2000 nor the 2003 load rating analyses included a determination of the capacity of the girders and bridge legs; thus, the load rating analyses did not account for the deterioration of the girders and legs that was documented in the inspection reports. Neither the 2000 nor the 2003 load rating analysis resulted in the posting of a load restriction.

The FHWA also identified concerns with the most recent load rating analysis performed in 2014 by an engineering firm. This analysis was based on the 2013 inspection report, which included an "Immediate Attention" recommendation to "perform an analysis of the stability of the structure assuming that the cross braces are nonfunctional" and resulted in a posted weight limit of 26 tons. In summary, the FHWA found the following regarding the 2014 load rating analysis:

- Holes and section loss on the bridge legs were not appropriately accounted for. The 2014 load rating used a method to distribute the section loss along the entire length of the legs by reducing the overall thickness of the leg web and flanges in capacity calculations to account for the missing material due to section loss and holes. This method failed to account for the localized effect of the section loss and holes due to corrosion of critical leg components that could lead to failure.[76]

- The capacity of the bridge legs was overestimated. In calculating the buckling stress of the legs, the 2014 load rating correctly discounted the structural contribution of the deteriorated cross-bracing that was no longer effective. However, the effective length factor (*k*-factor) used in the capacity calculations assumed that the legs were restrained against rotation at both the top and bottom and had lateral support in both directions.[77] Although the retrofitted steel cables would have provided some restraint, they lacked rotational restraint and lateral support. Thus, the incorrect *k*-factor resulted in an overestimation of the bridge's load capacity.

- A 3-inch asphalt surface was assumed in the dead load calculation based on the reported wearing surface thickness documented in the 2013 inspection report.[78] An FHWA calculation of dead load using the weight of

[76] Although technically an acceptable method to evaluate global behavior of the leg, this method did not account for the excessive corrosion in the bridge legs noted in the 2005–2013 inspection reports or the local stresses and instabilities around the corrosion holes documented in the inspection reports.

[77] A *k-factor* is the effective length factor used to account for the unbraced length of a column and its ability to resist buckling.

[78] *Dead load* is the total weight of the various structural members and the weights of any objects permanently attached to the structure.

the asphalt wearing surface as measured postcollapse was 14.3% higher than the dead load used for the bridge as designed and 17.2% higher than the dead load used in the 2014 load rating. The additional dead load reduced the bridge's available capacity to carry vehicular loads and was not accounted for in the 2014 load rating.

- The capacity of the transverse tie plates at the top of each shoe was never analyzed, and local effects were not considered. The bridge inspection reports did not provide sufficient data identifying the transverse tie plates as needing reevaluation due to deterioration, nor did they provide the detailed section loss measurements needed for this calculation.

- As designed, the Fern Hollow Bridge had the capacity to carry legal highway loads in the commonwealth of Pennsylvania.

1.13 Postcollapse Actions

1.13.1 Pennsylvania Department of Transportation

Immediately following the collapse of the Fern Hollow Bridge, PennDOT identified five other bridges with K-frame superstructures and FCMs in Pennsylvania and conducted field examinations to verify the most recent inspection findings for those bridges. Due to the extensive deterioration on the legs of the Fern Hollow Bridge, PennDOT also conducted a file review of other non-FCM K-frame bridges and bridges with steel bents by examining inspection reports, photographs, and sketches for corrosion. No issues requiring immediate follow-up were found with the K-frame bridges, but PennDOT determined that better inspection documentation of steel structures was needed.

On November 14, 2022, PennDOT published a Technical Bulletin updating Pennsylvania's Bridge Safety Inspection Program and its Bridge Maintenance Program (PennDOT 2022d). Among other changes, the Technical Bulletin reiterated the expectation of cleaning steel sections to accurately establish section loss; instituted a statewide task to verify bridge wearing surfaces thicknesses; addressed the need to consider bridge member deterioration, damage, and other defects for load ratings; revised the timeline for maintenance priorities; added inspection procedures for UWS bridges; and created a QC verification checklist.

1.13.2 City of Pittsburgh Department of Mobility and Infrastructure

According to January 26, 2023, and October 18, 2023, statements from DOMI, several changes have been made to its processes to improve management of its City-owned bridges. DOMI has increased its staff in the Bridges and Structures Division. It has hired a deputy chief engineer, project engineer, and staff engineer, and was conducting interviews for the positions of bridge maintenance supervisor and project manager as of its October 2023 statement. The proposed 2024 budget includes four new positions to establish a bridge maintenance division.

In coordination with PennDOT and a bridge inspection firm, DOMI has funded additional load rating analyses of City bridges that are covered under the NBI program. As of February 2024, 12 updated analyses had been completed, four were in progress, and several more were scheduled to be completed by the end of the year on the bridges covered under the NBI program. Additional load rating analyses performed by an engineering firm and City staff have been completed for 18 "local responsibility" vehicular bridges.[79] As a result, all vehicular bridges in the City have a current load rating analysis on file. City staff are also updating load rating analyses on 21 local-responsibility pedestrian bridges.

DOMI worked with PennDOT and the Southwest Pennsylvania Commission to advance $50 million in funding for a rehabilitation project on the Charles Anderson Bridge, which was closed on February 1, 2023, because of deterioration and an updated load rating analysis. Updated load rating analyses have led to additional lane restrictions on two other bridges (Swindell Bridge and North Avenue/Brighton Road Bridge), and rehabilitation/replacement plans are being developed for these bridges.

DOMI and PennDOT have coordinated an open-end design agreement for City bridge preservation projects. The intent of this agreement is to allow the City to efficiently issue work orders for preservation and smaller bridge replacement projects. Consultant selection is underway and engineering work will begin in 2024. Local spending on bridge inspection, maintenance, and repair has quadrupled over the last 12 months compared to yearly spending from 2018 to 2021. During the 1-year period of August 2022 through July 2023, the City spent $1.267 million on bridge inspection, maintenance, and repair, more than the amount spent during the 4-year period of 2018 through 2021 ($1.199 million total).

[79] "Local responsibility" bridges include vehicular bridges less than 20 feet long and non-vehicular bridges.

As of the end of 2023, 12 of 13 bridges with leaking expansion dam seals have received new replacement seals.[80] In the fall of 2023, cleaning of the scuppers and joints of 29 bridges began, and this work is expected to be completed in the spring of 2024.

1.14 NTSB Recommendation

Based on initial findings of this investigation, in May 2023, the NTSB published a report addressing the lack of maintenance on UWS bridges and the resulting corrosion (NTSB 2023). The NTSB found that the legs of the Fern Hollow Bridge experienced significant deterioration and section loss that were noted in the inspection reports. The deterioration and section loss resulted from the continual accumulation of water and debris, which prevented the development of a protective patina. As a result, the NTSB issued Safety Recommendation H-23-13 to the FHWA:

> 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 (currently classified Open—Initial Response Received).

In response to Safety Recommendation H-23-13, on July 19, 2023, the FHWA issued a memorandum titled “ACTION: Inspection Finding Follow-up Actions for Uncoated Weathering Steel Bridges.” This memorandum and the FHWA’s response to Safety Recommendation H-23-13 are discussed further in section 2.3.

[80] (a) *Expansion dams* are steel devices in bridge decks that allow the bridge to expand and contract as temperatures change, and that allow for rotation as the bridge deflects under traffic loads. Typically, an expansion dam has a rubber or neoprene seal in the opening that is flexible to handle the expansion and contraction, while preventing water from flowing down through the opening. Over time, dam seals tend to become torn, dislodged, or deteriorated and begin to leak, allowing water to flow down to the underside of the deck. (b) The City was not able to replace the modular expansion seal for the Bloomfield Bridge. The City is planning a preservation project within the next 4 to 5 years to fully replace modular dams.

2 Analysis

2.1 Introduction

On Friday, January 28, 2022, the Fern Hollow Bridge collapsed about 100 feet into the park below. At the time of the collapse, an articulated transit bus and four passenger vehicles were on the bridge. A fifth passenger vehicle drove off the east bridge abutment after the collapse began. The bus driver sustained minor injuries and two bus occupants were uninjured. Of the six passenger vehicle occupants, two sustained serious injuries, one sustained a minor injury, two were uninjured, and the injury status of one was unknown. This analysis first discusses those factors that can be excluded as causal or contributory to the bridge collapse. Then, the analysis examines the critical elements of the collapse sequence and evaluates the following safety issues:

- Lack of action on repeated recommendations from the bridge inspection reports, including the City's failure to maintain and repair the Fern Hollow Bridge and PennDOT's failure to ensure that the City completed the maintenance and repairs specified in the recommendations from the bridge inspection reports.

- PennDOT's ineffective bridge inspection program, which used bridge inspection methods and measures that were noncompliant with FHWA and AASHTO guidance, failed to identify all of the bridge's FCMs, and produced inaccurate bridge load rating calculations.

- Insufficient oversight by the City, PennDOT, and the FHWA of their responsibilities within the bridge inspection program to detect and prevent bridge failures.

As a result of the investigation, the NTSB established that the following factors did not cause or contribute to the Fern Hollow Bridge collapse:

- *Uncoated Weathering Steel*: The design plans for the K-frame Fern Hollow Bridge called for the use of UWS, which is suitable for bridge construction when used under appropriate conditions and properly maintained.

- *Bridge Design*: The as-designed K-frame bridge without corrosion damage and section loss in the leg web, transverse tie plates, flanges, and stiffeners, and with a 3-inch wearing surface, had the capacity to support the expected loads on the bridge, as demonstrated by the evaluation of the load rating analysis and the FE modeling. Further, the Fern Hollow Bridge successfully carried these loads for more than 50 years, with a load posting first occurring in 2014 to reduce the vehicle weight limit to 26 tons.[81]

- *Fabrication of Materials Used*: Although several steel plates used in constructing the bridge were noncompliant with ASTM International standards (specifically, tensile strength and chemical composition), the deficiencies were either minimal, their effects were small, or the noncompliant plates were not in the area where the collapse initiated. Also, even though the welds at the top of each leg and at the end plate of each leg used in the construction of the bridge were different from those specified in the design plan, the discrepant welds did not cause the bridge collapse. The FE modeling showed that the reduced bridge capacity resulting from these welds was minor.

- *Deterioration of Welds*: Investigators found cracks in the welds at the tops of the legs. Although the time of the initial cracking could not be determined, the rust that was observed in and around the cracks suggested that the cracks occurred before the collapse. Further, the cracks were not near the collapse initiation point.

- *Qualifications of Personnel*: The FHWA confirmed that all team leaders for the 2005–2021 bridge inspections met the NBIS and PennDOT qualifications required at the time of the collapse.

Therefore, the NTSB concludes that 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.

The NTSB documented the emergency response timeline. The initial 911 call was received at 6:37 a.m., and police were on scene within 5 minutes of being dispatched, followed within minutes by fire and emergency medical services personnel. Gas lines were turned off and homes were evacuated as a safety precaution. The NTSB concludes that the emergency response was timely and adequate.

[81] The weight of the transit bus was about 43,820 pounds, which was compliant with the maximum posted weight limit for a single vehicle on the bridge. The passenger vehicles each had weights under 10,000 pounds.

2.2 Bridge Collapse Sequence of Events

2.2.1 Overview

The initial examination of the postcollapse physical evidence focused on how the bridge sections collapsed and their final rest locations. As seen in the overhead orthomosaic image in figure 4 (section 1.1), the east end of the bridge was displaced much farther from its abutment than the west end of the bridge. These displacements indicated that the west end of the bridge collapsed downward first and pulled the center and east spans down toward the collapse point, creating the larger separation between the east span and the east abutment.

The video footage from the transit bus's curbside, rear-facing camera, which pointed rearward down the right side of the bus (toward the west), provided further evidence of the initiation of the collapse. The video footage showed the initial indication of the collapse of the west end of the bridge as the eastbound bus approached the center of the bridge. The video showed a downward vertical drop of the bridge railing on the southwest side of the bridge. Near this time, the forward-facing camera on the transit bus did not show any changes in the east end of the bridge, but the video image pitched upward slightly, corresponding with the initial vertical drop of the bridge behind the bus. Almost 2 seconds later, the video footage from the curbside, rear-facing camera showed the west end of the bridge separated from the west abutment. About 0.5 seconds after the separation of the west abutment, the forward-facing video footage showed the east expansion joint just beginning to separate from its connection to the east abutment.

The video footage confirmed the initial assessment that the collapse sequence started on the west end of the bridge. Subsequent examination focused on the main structural components of the bridge to determine the source of the failure.

2.2.2 Examination of Postcollapse Bridge Structures

The detailed postcollapse bridge examination focused on the main bridge structures including the abutments, the two bridge girders and the floor system supporting the bridge decking, the four bridge legs, and the thrust blocks.

Postcollapse, both the west and east abutments were intact, but the girders and floor system were pulled away from both abutments. There was no evidence of primary fractures in the girders or in the floor system in the postcollapse bridge wreckage.[82] However, bending and secondary fractures consistent with damage caused by and during the collapse were observed in the girders and in several of the floor system supports. Thus, the girders and floor system did not show evidence indicative of initiating the collapse.

All bridge legs showed evidence of section loss due to corrosion in their web, flanges, and stiffeners. The southwest leg (B1R) sustained more damage during the collapse than the southeast leg (B2R) and the legs on the north side of the bridge (the northwest leg [B1L] and northeast leg [B2L]). Although the northwest leg (B1L) and northeast leg (B2L) were corroded, they remained relatively intact during the collapse. On the southeast leg (B2R), the web on the first panel above the shoe fractured and the span 3 side flange was bent into the web, likely the result of larger bridge components coming down on top of the leg. The southwest leg (B1R) was bent at a 90-degree angle near the transverse tie plate at the top of the shoe. The flange from the span 2 side was completely separated from the web in this area.

Although holes in the web of the legs and section loss in the transverse tie plates were visible postcollapse as well as documented in the inspection reports, 3D laser scanning of the lower portions of all four legs showed the extent of the corrosion and large reduction in remaining material in multiple locations. The shoes of each leg were corroded such that the section loss resulted in holes at the toe and reduced material thickness throughout the shoe. Additionally, on all four legs, panel 1—the web above the transverse tie plate—showed indications of corrosion. The corrosion damage to the southwest leg (B1R) was the most extensive. Specifically, much of the southwest leg (B1R) transverse tie plate was corroded such that only about 12.5% of its thickness remained as compared to its thickness when it was built (an 87.5% reduction in cross-sectional area). The southeast leg (B2R) transverse tie plate was also corroded but to a lesser extent than that of the southwest leg (B1R; see figure 36).

[82] A *primary fracture* is a fracture that was part of the initial sequence of the collapse. A *secondary fracture* is a fracture that occurred as a consequence of the collapse. For example, the bridge falling into the valley, impacting the ground and other bridge structures, caused numerous secondary fractures.

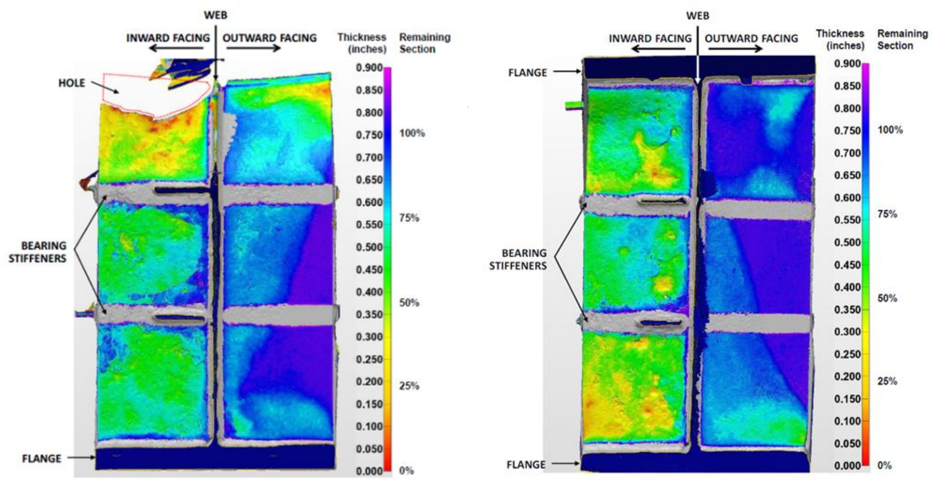


Figure 36. Comparison of southwest leg (B1R) transverse tie plate (left) and southeast leg (B2R) transverse tie plate (right).

The next section focuses on the southwest leg (B1R) given its damage and deteriorated condition relative to the other bridge legs.

2.2.3 Collapse of the Southwest Leg (B1R)

The corroded transverse tie plate was at a critical location where the leg tapered at an angle into the shoe to form the connection with the thrust block. The transverse tie plate may appear similar to the other transverse stiffeners along the length of the leg, but it was designed with a piece of steel that was thicker (0.75-inch versus 0.4375-[$^{7}/_{16}$]-inch) and wider (the tie plate was present on the inward and outward face of the web, whereas the other stiffeners were present only on the inward face of the web), indicating that it needed more strength than the other transverse stiffeners to provide rigidity to the web and dual flange design at this critical location in the leg geometry (refer to figure 10).

Further, the shape of the leg at this location—with the flanges transitioning to a steeper angle—resulted in tensile forces within the transverse tie plate. Because the steel transverse tie plate was also nonredundant, it should have been identified as an FCM (see section 2.4.2 for a discussion of FCM identification). In addition, with its proximity to the ground, it was vulnerable to the buildup of debris—such as leaves and dirt—and water, which flowed down the legs due to the drains being clogged.

Postcollapse, near the transverse tie plate, the southwest leg (B1R) was bent at a 90-degree angle, likely resulting from a loss of structural integrity due to the complete separation of the flange from the web and tie plate at this location. Because the transverse tie plate held both flanges together with the web and because both the web and transverse tie plate were severely corroded at this location, with large holes visible in the web, the corrosion and section loss in the transverse tie plate reduced its ability to resist the tensile loads, causing failure. The failure of the fracture-critical transverse tie plate resulted in the separation of the bottom flange (span 2 side flange) and subsequently the failure of the southwest leg (B1R).

The FE modeling confirmed this failure point. When the thicknesses of the transverse tie plate, flanges, and web from the design plan without any corrosion were used in the FE model, the model showed that the bridge had sufficient strength to withstand the vehicular loads at the time of the collapse. When these portions of the bridge were modeled with the section loss and holes that were documented postcollapse—which were similar to those documented in the inspection reports—they did not have sufficient strength to withstand the loads that were on the bridge at the time of the collapse. Therefore, the FE modeling confirmed that the failure point of the bridge was the deteriorated and corroded transverse tie plate in the southwest leg (B1R) at the transition between the leg and the shoe.

The final rest position of the bridge components, the transit bus video, and the extensive damage to the southwest leg (B1R) indicated that the collapse initiated at the west end of the bridge, specifically the southwest leg (B1R). The NTSB concludes that the Fern Hollow Bridge collapsed due to the extensive corrosion and section loss of its FCMs, 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.

2.3 Lack of Action on the Recommendations Made in the Fern Hollow Bridge Inspection Reports

As the owner of the Fern Hollow Bridge, the City was responsible for making sure it was inspected as required and was also responsible for its maintenance. Since 2005, the Fern Hollow Bridge had been subject to nine routine inspections that included FCM inspections performed at 24-month intervals. Beginning in September 2014, the Fern Hollow Bridge was also subject to interim inspections focused on FCMs, which were performed in the years between the routine inspections, thus reducing the inspection interval to every 12 months. The interim inspections were required based on (1) the January 2014 load rating analysis that resulted in a 26-ton posted load limit implemented in response to a recommendation from the 2013 inspection report, and (2) a superstructure condition rating of 4 (Poor) requiring annual inspections. The superstructure condition rating was a 4 starting in 2011, which should have triggered annual inspections; however, no inspection was conducted in 2012, and the NTSB was not able to determine why this additional inspection was not performed.

The inspection reports from 2005 through 2021 documented holes in the web and section loss in the longitudinal and transverse stiffeners on all four bridge legs.

The 2005 inspection report, performed more than 16 years before the collapse, stated that the UWS legs were in "fair to poor condition." The report noted that large amounts of rust had accumulated in the intersections of the transverse stiffeners and that the moist rust was generating severe corrosion of surrounding structural components. It described all of the bridge legs as having severe corrosion and specifically noted the 2-inch-by-4-inch hole and knife edging of the stiffeners in the southwest leg (B1R). Transverse stiffeners on other bridge legs exhibited similarly severe corrosion with up to 75% section loss.

Deterioration of the bridge legs continued to advance. The 2013 inspection report described severe deterioration in the west legs with areas in the web having 100% section loss. Photographs documented an 11-inch-by-11-inch hole in the web above the transverse tie plate on the southwest leg (B1R; left photograph in figure 37). In 2021, the hole above the transverse tie plate on the southwest leg (B1R) was reported to be 12 inches by 12 inches (right photograph in figure 37). In every inspection report since 2005, corrosion and section loss in the bridge legs were recorded.

Figure 37. Corrosion damage including areas of 100% section loss on southwest leg (B1R) in panel 1 above the transverse tie plate. (Source: 2013 inspection report [left photograph]; 2021 inspection report [right photograph])

Clogged drains and debris accumulation were also noted in almost every inspection report. The 2005 report noted that water leakage from the drainage system of the bridge decking was allowing water to drain directly onto the southwest leg (B1R). This buildup of water and debris prevented a protective patina from forming on the bridge. In 2009, a rehabilitation project to replace the bridge downspouts was completed, and the October 2009 routine inspection report described the drains as being clear. However, the 2011 inspection report noted that some of the drains had become clogged again. The 2020 inspection report specifically stated that the "legs and cross-bracing are deteriorating at an accelerated rate, due to malfunctioning drainage systems and deterioration, contamination and seepage through the deck concrete."

The inspection reports also contained numerous and repeated maintenance recommendations. (Refer to figure 27 for a summary of maintenance recommendations from the 2005–2021 inspection reports.) Except for the 2009 inspection report, every routine inspection report recommended that the clogged drainage inlets on the bridge deck be cleaned. Recommendations to clean debris from the surfaces of the superstructure appeared in all of the inspection reports as routine items to be completed within the next work cycle. Beginning in 2007, recommendations to repair or reinforce the section loss in the bridge legs were noted repeatedly in the inspection reports and assigned a priority code of 2 as items to be completed within the routine inspection interval, which was 24 months; however, the section loss in the bridge legs was never repaired or reinforced. The water issues and clogged drains were addressed only once between 2005 and 2022 and were generally considered to be routine repair recommendations.

In accordance with PennDOT's Publication 100A, in effect at the time of the collapse, the bridge inspectors assigned each maintenance and repair recommendation a priority code ranging from 0 (immediate response required, within 7 days) to 5 (as per existing maintenance schedule, within the next work cycle) (PennDOT 2022c). From all of the inspection reports from 2005 to 2021, only four maintenance and repair items were coded as priority 0, none of which addressed the corrosion on the bridge legs. Work orders and inspection reports indicated that maintenance items coded as 0 or 1 were completed (two regarding correction of the load-posting signage, one recommending removal of a corroded light pole, and one recommending removal of a corroded cross-brace that had begun to fall off the bridge); however, many of the other maintenance and repair items recommended in inspection reports were never corrected by the City, despite the limited maximum time frames associated with their priority codings.

Maintenance and repair recommendations with priority codes 2 through 5 were not received with the same urgency as recommendations with priority codes 0 and 1. PennDOT has a tracking system that tracks maintenance and repair recommendations as part of its bridge oversight program. However, its tracking system only produces reports on items with priority codes 0 (Critical) and 1 (High). Items with the lower priority codes 2 through 5 "fall off of any type of report," according to the assistant chief bridge engineer at PennDOT.

At the time of the collapse, the City did not have a preventative maintenance schedule to clean out the stormwater drainage system, did not have in-house resources to complete such work, and could not produce any records indicating that a contractor had been hired to clean out the stormwater drainage system prior to January 2022, except for the 2009 rehabilitation project wherein the downspouts were replaced and the drains were cleaned.

Other aspects of the 2009 rehabilitation project were changed or not completed. Instead of replacing the cross-bracing as proposed in the rehabilitation plan, steel cables were installed as an interim solution until the bracing could be replaced, which required re-tensioning in later years. However, there was no evidence that the cross-bracing was ever replaced. The 2009 plan also called for the lower portions of the legs and lower cross-braces to be blast-cleaned and painted with a rust-inhibitive coating. However, there was no evidence that the coating was ever applied to these areas of the bridge. The application of such a coating is a common countermeasure used to mitigate corrosion in areas where a protective patina on the UWS has not formed, and it would likely have helped to slow or even stop the progression of destructive corrosion in these areas. A coating was applied to critical areas of a similar K-frame bridge in West Virginia, and no corrosion was observed on its legs.

The City had a contract in place for structural rehabilitation from June 1, 2019, through May 31, 2022, which included preventative maintenance on bridges. The City did not provide any documentation of any repair services being requested or performed on the Fern Hollow Bridge during that time period, and there was no evidence that the other maintenance recommendation items identified to be accomplished within the next 24 months or before the next routine inspection, such as replacing/reinforcing the stiffeners and repairing web that had rusted through, were ever addressed.

The inspection reports demonstrated that the corrosion, deterioration, and section loss on the web and transverse stiffeners, specifically the transverse tie plate in the southwest leg (B1R) and the web of panel 1, were accelerating. The clogged drains led to the water seeping through the deck and down the bridge legs, and the continual accumulation of water and debris on and around the bridge structure prevented the formation of the protective patina that would have resisted corrosion. The loss of material in an FCM was causal to the bridge collapse. Inspection reports repeatedly identified maintenance and repairs that were needed on the Fern Hollow Bridge legs, but few were accomplished because they were not considered urgent. The NTSB concludes that the significant corrosion and section loss on the southwest leg (B1R) resulted from the failure of the City to act on the repeated maintenance and repair recommendations documented in inspection reports from 2005 to 2021, leading to progressive deterioration and structural failure.

Since the collapse, DOMI (within the City) has reported that it has made changes to its bridge maintenance program. According to an October 2023 update, from October 2022 through October 2023, 25 maintenance and repair work orders have been issued and completed through an on-call bridge maintenance contractor. By the end of 2023, 12 bridges with leaking dam seals had received new replacement seals. DOMI completed scupper cleaning and joint flushing on multiple bridges in 2022 and 2023. Local spending on bridge inspection, maintenance, and repair quadrupled between August 2022 and July 2023 ($1.267 million) compared to yearly spending from 2018 to 2021 ($1.199 million total). Additionally, DOMI and PennDOT have coordinated an open-end agreement for City bridge projects that is intended to allow the City to efficiently issue work orders for preservation and smaller bridge replacement projects. PennDOT has also addressed maintenance activities since the bridge collapse. PennDOT Publication 238 already required inspection organizations to review annually and determine bridges' maintenance, rehabilitation, and replacement needs.[83] In the November 2022 Technical Bulletin issued as a result of the collapse, PennDOT directed that in the next annual review, inspection organizations are to review UWS bridges and focus on the following factors:

- Was adequate cleaning performed during the safety inspection to establish section losses and corresponding maintenance needs? If not, is there an immediate need to reinspect the bridge and re-evaluate the load rating of the bridge?

- Are the Priority 2 maintenance items appropriately classified, i.e., are there any items that should be Priority 0s or 1s?

- Are crevices within the steel framing creating conditions that have caused or will promote and accelerate corrosion and section loss of the steel? If so, is there a need to implement crevice sealing actions?

- Are water and debris "traps" within the steel framing creating conditions that have caused and/or will promote and accelerate corrosion and section loss of the steel? If so, are these areas a focus of regular cleaning and/or is there a need to implement retrofits to eliminate the "traps" or initiate other corrosion mitigation?

- Are bridge joints leaking? If so, is there a planned maintenance action to repair the joints and paint the ends of the steel members at the joint locations?

- Is the deck drainage system directing drainage onto the steel framing? If so, is there a planned maintenance action to repair the drainage system? (PennDOT 2022d).

Following the bridge review, the districts are to notify the PennDOT chief bridge engineer that the review has been completed as well as provide a summary of any actions that were or will be taken in response to the focused items.

[83] PennDOT 2022a, Section 6.2.4.2, "QC of Scheduled Bridge Maintenance;" Priority 2 through 5, "Rehabilitation and Replacement Needs."

PennDOT has also updated its guidance including Publication 238 (*Bridge Safety Inspection Manual*), Publication 55 (*Bridge Maintenance Manual*), and Publication 15M (*Design Manual Part 4 Structures*) to include additional information on weathering steel and preventative maintenance (PennDOT 2022a, PennDOT 2022e, PennDOT 2019).

In May 2023, the NTSB published a report addressing the lack of maintenance on UWS bridges and the resulting corrosion. As a result, Safety Recommendation H-23-13 was issued to the FHWA asking it to develop a risk-based, data-driven process for state departments of transportation and other bridge owners to help them identify, prioritize, and perform previously identified follow-up actions documented in inspections of bridges with UWS components. On July 19, 2023, the FHWA issued a memorandum titled "ACTION: Inspection Finding Follow-up Actions for Uncoated Weathering Steel Bridges" instructing all state departments of transportation and other bridge owners to:

1) Identify all bridges in their inventory, regardless of ownership, with UWS components in the primary load path.

2) Categorize the identified UWS bridges into groups based on condition ratings.

3) Report specific bridges to the FHWA.

4) By December 2024, ensure that work items addressing deficiencies resulting from poor UWS performance on the reported bridges have been completed, and verify that the current load rating for the bridges adequately and appropriately considers the documented deterioration and any completed work; if not, update the load rating (FHWA 2023b).

Figure 38 shows the process developed by the FHWA to inspect, inventory, and evaluate bridges and bridge components fabricated from UWS. The NTSB concludes that in response to NTSB Safety Recommendation H-23-13, the FHWA 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. The FHWA's issuance of the July 19, 2023, memorandum addresses the intent of Safety Recommendation H-23-13, which is classified Closed—Acceptable Action.

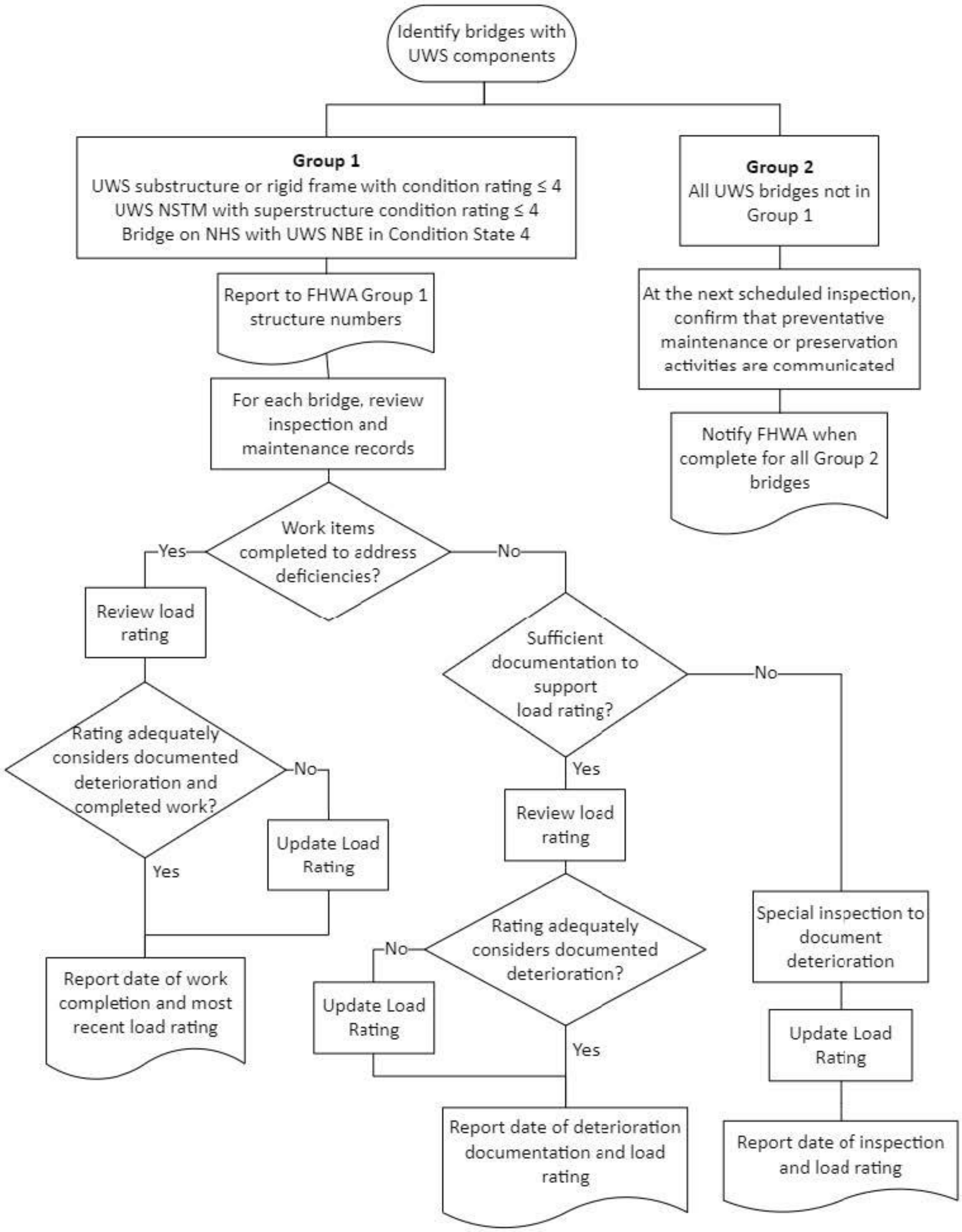


Figure 38. FHWA process to inspect, inventory, and evaluate bridges and bridge components fabricated from UWS. (Source: FHWA 2023b)

2.4 Ineffective Bridge Inspection Program

This section describes deficiencies in the quality of the inspections, the identification of FCMs, and the calculation of the load rating for the Fern Hollow Bridge.

2.4.1 Quality of Inspections

The Fern Hollow Bridge inspections and inspection reports were performed by PennDOT contractors on behalf of the City. The review of the inspection reports indicated that although the bridge inspectors documented the section loss throughout the bridge, they did not thoroughly measure and document the thickness of the remaining sections. The amount of remaining material is critical information to collect because it is necessary to calculate accurate load ratings and evaluate the safety of the bridge. Guidance in the 2002 published version of the *BIRM* states, "When inspecting steel or iron structures, determine the extent and severity of corrosion, carefully measuring the amount of cross section remaining" (FHWA 2002).

Further, many inspection report photographs showed corrosion and section loss on the bridge legs; however, the inspection reports did not contain evidence that the corroded material was removed and that only the bare, remaining metal was established before obtaining measurements. The presence of the corrosion would lead to incorrect measurements of the section loss of any remaining section. Specifically, the failure to remove the corroded material would lead to an overestimation of the amount of material remaining. Although accurate measurements of the section loss and remaining material would have provided the City with additional information on the accelerating damage to the bridge legs, the inspection reports already identified these problematic areas and prescribed that maintenance be completed, either before the next inspection or within 24 months. Because the City did not complete needed repairs to the holes and section loss on the web or stiffeners as prescribed by the inspection reports, it is unlikely that accurate remaining section measurements would have changed its response.

As part of the bridge inspection process, inspectors are required to provide an NBI condition rating for the superstructure. The superstructure of the Fern Hollow Bridge was rated a 5 (Fair Condition) from 2005 through 2009 and then dropped to a 4 (Poor Condition) from 2011 until the collapse. According to the FHWA's postcollapse analysis, the more appropriate rating, given the condition of the superstructure documented in the inspection reports, would have been a 3 (Serious Condition) or a 2 (Critical Condition). Further, in the 2018 through 2020 inspection reports, inspectors used the terms "poor to critical" when describing the condition of the bridge legs and included documentation of the corrosion, section loss, and holes in multiple areas of the web, flanges, and stiffeners. The use of the "poor to critical" terminology indicates that the condition in several areas of the superstructure was worse than the assigned condition rating of 4 (Poor Condition).

Guidance in the FHWA's *Coding Guide* and *BIRM* for these inspection descriptions of the condition of the bridge legs should have resulted in a condition rating no better than 3 (Serious Condition; FHWA 1995, FHWA 2023a). This condition rating reflects that local failures are possible, which would have been the best credible rating given the extent of the section loss and size of the holes in the bridge legs documented in the inspection reports. A condition rating of 2 (Critical Condition) could also have been justified by inspectors given the extensive deterioration of the bridge legs and the fact that the deterioration was accelerating. A bridge that receives a condition rating of 2 would be considered to be in Critical Condition, and unless closely monitored, it may be necessary to close the bridge until corrective action is taken.

In addition to the general condition rating of the bridge, the Moving Ahead for Progress in the 21st Century Act (MAP-21) requires element-level bridge condition data for certain bridges, including the Fern Hollow Bridge.[84] These element-level data were collected and reported in the 2019, 2020, and 2021 inspection reports, and all four bridge legs were assessed to be in CS4 (Severe Condition), which is the worst possible rating using this process. Further, CS4 for defects in steel elements calls for a structural review, or if a structural review has been performed, the results should indicate how the identified defects affect the serviceability of the element or bridge (AASHTO 2019). No records were located to indicate that a structural review was conducted as a result of this element-level rating of the bridge legs, nor was any such recommendation made in the inspection reports.

In summary, although inspection reports identified and recommended corrective actions in several areas, the evaluation of these inspection reports identified several deficiencies in the quality of the inspections completed on the Fern Hollow Bridge. First, although section loss was reported, critical measurements of the remaining material were not provided. Second, the measurements of section loss were likely underreported because the corrosion was not removed in accordance with the guidance in the *BIRM*. Third, given the degree of section loss, the overall bridge condition rating was overestimated when evaluated at a 4 (Poor) rating. A change in the overall condition rating from 4 (Poor) to a more accurate rating of 3 (Serious) or 2 (Critical) would have resulted in closer monitoring and potentially the closure of the bridge until corrective action was taken. Finally, the element-level condition rating of the bridge legs was properly assessed at CS4 (Severe) between 2019 and 2021, but an additional structural evaluation was never performed following the 2014 structural review and load rating. Had these aspects of the

[84] MAP-21 (P.L. 112-141) was signed into law on July 6, 2012.

inspection been performed correctly, a revised load rating for the bridge structure would have been recommended. The NTSB concludes that multiple inspectors of the Fern Hollow Bridge, contracted by PennDOT on behalf of the City 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.

Performing inspections that are compliant with the guidance in the *BIRM* and *MBE* is a basic operating principle of the bridge inspection program, as is the requirement to have a robust QC program to ensure that deficiencies in an inspection program are identified before failure occurs. As the oversight organization responsible for the state's bridge inspection program, PennDOT has expanded its QC program so that all bridges with a condition rating of 4 or worse for the deck, superstructure, substructure, channel, or culvert must be reviewed by a professional engineer independent of the safety inspection report before being accepted into Pennsylvania's Bridge Management System.[85] The previous PennDOT requirement was to review bridges with a condition rating of 3 or worse. Additionally, CS ratings for elements that were collected beginning in 2019 are also being added to the Bridge Management System. Elements with element-level CSs of 4 are now required to be recorded by inspectors and reviewed by PennDOT to ensure that maintenance requirements have been completed.

PennDOT has also developed and instituted an Inspection Report Quality Control Verification Checklist to improve inspection reporting (PennDOT 2022d). The team leader's review must ensure that all items in the verification checklist have been addressed. Of note and particularly relevant to the Fern Hollow Bridge collapse are the following:

- Were all necessary components inspected and notes updated for changes? Do condition codes match notes and photos?
- Have bridge members been sufficiently cleaned to establish remaining member sections and section loss?
- Have maintenance needs been properly identified and in general agreement with Pub100A guidance?

[85] Pennsylvania's Bridge Management System, also called BMS2, captures inspection data and optimizes the use of bridge inspection, maintenance, rehabilitation, and replacement information.

- Has the appropriate load rating method of analysis (i.e., simplified vs advanced) been used for the bridge conditions?
- If there are portions of any elements in CS4 that warrant a structural review, has this been completed?

According to PennDOT, the purpose of the QC verification checklist is to use a standardized format to ensure that key inspection items have been completed. In addition, the checklist must be signed and dated at the top of the form with fields that include Structure ID, Inspection Type, Inspection Date, QC Review Completed By, and Date, providing accountability and verification of the review.

2.4.2 Fracture-Critical Member Identification

A second issue contributing to the ineffectiveness of the bridge inspection program involves the identification of the FCMs for the Fern Hollow Bridge. According to 23 *CFR* 650, an FCM is made of steel, fully or partially in tension, and nonredundant, meaning that failure of the member will cause the bridge to partially or fully collapse. Because the consequences of failure are so severe, FCMs are subject to hands-on inspection (inspection within arm's length of a component) that includes visual and NDE methods. An important and required part of the FCM inspection is a well-documented inspection plan that identifies all FCMs in advance and ensures that they are inspected properly and thoroughly during each FCM inspection.

For the Fern Hollow Bridge, the girders, floor beams, and bridge legs including the transverse tie plates were steel, in tension, and nonredundant, and therefore were FCMs. Early inspection reports (2005–2009) for the Fern Hollow Bridge included handwritten notes about FCMs but did not identify the legs as FCMs. Although the Fern Hollow Bridge inspection reports included a Fracture-Critical Identification Framing Plan beginning in 2011 that labeled the floor beams and portions of the girders as FCMs, this plan as well as the updated diagram from the 2016 Fatigue and Fracture Bridge Inspection Plan incorrectly omitted the legs as FCMs. The handwritten notes, Fracture-Critical Identification Framing Plan, and Fatigue and Fracture Bridge Inspection Plan were all developed by PennDOT contractors on behalf of the City. The engineer who signed the 2016 Fatigue and Fracture Bridge Inspection Plan stated that he thought the bridge legs were in compression and therefore not fracture-critical. The Fracture-Critical Identification Framing Plan serves as a guide for inspectors in the field—including the engineer who signed and sealed the 2016 Fatigue and Fracture Bridge Inspection Plan as well as the 2015–2019 inspection reports—to identify members that have been designated as FCMs and ensure that all FCMs are properly inspected.

Omission of FCMs is less likely to occur for bridges built after 1978, when guidance was introduced specifying that the bridge design engineer is responsible for identifying which bridge members are FCMs (AASHTO 1986). Although it was initially published as guidance and was thus viewed as a recommended practice, it is now a requirement that "the Engineer shall have the responsibility for identifying and designating on the contract plans which primary members or portions thereof are fracture-critical members (FCMs)" (AASHTO 2020).[86]

The inspection reports were inconsistent in their treatment of the bridge legs. In some instances, such as the 2016 inspection report, the bridge legs were referred to as FCMs, and it appeared that a hands-on inspection was performed on the legs. Other reports lacked this detail, and it was not clear whether a hands-on inspection was performed on the entirety of the legs. In some inspections where the bridge legs were included in the inspection report in the "fracture-critical members and intersecting welds" section, the inspections of the legs focused only on the condition of the intersecting welds. The NTSB concludes that 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, PennDOT contractors did not properly identify the bridge legs, including the transverse tie plates, as FCMs (NSTMs), and as a result, the legs did not consistently undergo a more in-depth, hands-on FCM inspection as required by 23 *CFR* 650 Subpart C.

As part of the investigation, the NTSB examined 10 other bridges in Pennsylvania with designs similar to the Fern Hollow Bridge. These limited examinations found similar issues—although not as severe—to those observed on the Fern Hollow Bridge, including built-up debris, improper drainage, and corrosion. FCM plans were included in the inspection reports of the Fahy Bridge and the Shenango Road Bridge, which are both K-frame bridges constructed of UWS. The McCallum Street Bridge is a delta frame bridge, also constructed of UWS, that also included an FCM plan. The FCM plan identified the legs of the bridge as FCMs. The Murray Avenue Bridge, a painted steel K-frame design, was identified as a fracture-critical bridge; however, its legs were not labeled as FCMs even though they met all criteria and should have been labeled as such. The FCM plan for the Murray Avenue Bridge was updated following the examinations. The other six bridges did not contain FCMs.

As noted in section 2.3, inspection maintenance and repair recommendations are given a priority code in accordance with PennDOT Publication 100A. The publication contains several detailed examples for properly coding maintenance

[86] The next (10th) edition of the AASHTO *Load-and-Resistance Factor Design Bridge Specifications* will incorporate the term "nonredundant steel tension member" (NSTM).

recommendation items. In 2009, Publication 100A was updated to include "Severe Corrosion: Holes due to corrosion in FCM girder flanges, webs, or in truss members" as an example of a priority code 0 (Critical) item (PennDOT 2022c).

Beginning in 2007 and continuing until 2021, holes in the web and section loss on the transverse stiffeners were documented in the Fern Hollow Bridge legs, and recommendations were made for the holes and section loss to be repaired or reinforced. The recommendations were assigned a priority code of 2, meaning that they should be completed within the routine inspection interval of 24 months. Although maintenance and repair recommendations with a priority code of 0 (Critical) or 1 (High Priority) were completed, there is no evidence that action was taken on the priority 2 recommendations to repair or reinforce the holes and section loss in the legs. However, had the bridge legs, including the transverse tie plates, been properly identified in the Fracture-Critical Identification Framing Plan as FCMs, there was clear precedent (through the example in Publication 100A) for the recommendations to repair and reinforce the holes in the bridge legs to be assigned a maintenance priority code of 0 (Critical), requiring action within 7 days and compelling more scrutiny from the City and PennDOT. Because other recommendations with priority codes of 0 and 1 were eventually completed by the City, it is likely that action would have been taken on these recommendations. The NTSB concludes that had the bridge legs, including the transverse tie plates, been properly identified as FCMs, 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. Further, the NTSB concludes that if the City 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.

PennDOT has included items on its recently implemented QC verification checklist to confirm that the Fatigue and Fracture Bridge Inspection Plan is complete and that a hands-on inspection has been completed for all FCMs in accordance with this plan. Additionally, as PennDOT stated in its November 2022 Technical Bulletin, a higher percentage of larger structures with fatigue- and fracture-critical details will be selected for inspection as part of its QA program (PennDOT 2022d). The language contained in Publication 240, *Bridge Safety Inspection Quality Assurance Manual*, has been revised to indicate that special access requirements should not preclude selection of any bridge for QA inspection (PennDOT 2020). In other words, if a bridge is deemed appropriate for QA inspection, arrangements to provide inspectors access to the bridge should be made before the QA inspection process begins and the bridge should not be omitted from the QA process. Although these changes point to the importance of and reliance on the FCM design and the need to complete QA inspections of FCM bridges, the concern remains that all FCMs must be correctly identified in the Fracture-Critical Identification Framing Plan.

The failure to correctly identify the Fern Hollow Bridge legs as FCMs in the Fracture-Critical Identification Framing Plan and the Fatigue and Fracture Bridge Inspection Plan led to a failure to perform a hands-on, fracture-critical inspection of the bridge legs and a failure to assign more immediate priority codes to the repair/reinforce recommendations. By definition, failure of an FCM leads to a partial or full collapse of a bridge. At least one other K-frame bridge, the Murray Avenue Bridge, was identified as an FCM bridge where the legs were incorrectly omitted as FCMs in the FCM plan. Due to the safety risk associated with missed identification of an FCM, there is a need to ensure that all FCMs are correctly identified.

The NTSB concludes that the correct identification of FCMs 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. Therefore, the NTSB recommends that the FHWA 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 FCM (NSTM) inspection plans for bridges with nonredundant steel frame leg designs in their inventory, and update these plans as necessary to ensure that all FCMs, especially those in the legs, have been properly identified and accounted for in the FCM inspection plans and inspections.

Both the *BIRM* and the *MBE* provide guidance for inspecting FCM bridges. The *BIRM* discusses the significance of correctly identifying all FCMs and the procedures for inspecting each member. If the FCMs are identified in advance, the inspection team can focus on them with a hands-on inspection.[87] The Fracture-Critical Identification Framing Plan for the Fern Hollow Bridge incorrectly omitted the bridge legs and more specifically failed to identify the transverse tie plates as FCMs. The transverse tie plate on the southwest leg (B1R) was the initiation point of the collapse of the Fern Hollow Bridge.

Although the transverse tie plate at the top of the shoe was a critical component in the structural stability of the leg and the overall bridge, the Fracture-Critical Identification Framing Plan did not identify it as an FCM, nor did inspectors recognize the failure risk when they documented the section loss of the transverse tie plate. The transverse tie plate was in a region of localized tension due to the leg geometry and the transition of forces into the shoe. Its importance to the structural design of that region was further revealed by its thicker dimensions as compared to the nearby transverse stiffeners on the bridge legs. The bottom third of the leg and shoe were mainly in compression, with the exceptions of the transverse tie plate and the web in the area of the transverse tie plate, which were in tension. Although both the *BIRM* and the *MBE* address multiple concepts of bridge loading, neither of these manuals address the identification of bridge components in localized tension zones,

[87] FHWA 2023a, p. 7-115.

such as the tie plate region of the Fern Hollow Bridge, especially for portions of bridges that are globally in compression.

The NTSB concludes that bridge inspectors lack adequate guidance from the FHWA *BIRM* and AASHTO *MBE* on the proper identification of localized tension zones and tension components to correctly identify FCMs in preparation for and during bridge inspections. Therefore, the NTSB recommends that the FHWA update its *BIRM* 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. Further, the NTSB recommends that AASHTO update its *MBE* 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.

2.4.3 Load Rating

A third contributing factor to the ineffectiveness of the bridge inspection program involved errors in the load rating for the Fern Hollow Bridge. The posted load limit for the Fern Hollow Bridge was 26 tons. This limit was posted in 2014 following a load rating analysis conducted in response to an inspector recommendation in the 2013 routine bridge inspection report regarding the nonfunctional cross-bracing.

Investigators identified several issues with the methods used in the 2014 load rating analysis, including an incorrect assumption about the thickness of the asphalt wearing surface (see additional discussion in section 2.4.3.1), the use of an incorrect *k*-factor that resulted in overestimating the load capacity of the legs with only cables to stabilize them, and the distribution of the localized section loss across the entire length of the leg, which ignored local stresses due to the section loss. Had all of these factors been properly considered and the load rating been correctly calculated, the bridge's lack of capacity would have resulted in closure of the bridge.

First, the thickness of the wearing surface was assumed to be 3 inches in the 2014 load rating analysis. Postcollapse, the wearing surface thickness was measured at almost double this amount, causing a greater static (dead) load on the bridge that would have resulted in a load posting that was lower than 26 tons if the thicker surface had been accounted for.[88] Second, the load rating analysis assumed a *k*-factor for the leg buckling stress that was only appropriate when the cross-bracing for the legs was in place and effective. The cable bracing between the legs was not sufficient to provide lateral support, and therefore the *k*-factor that was used overestimated

[88] The as-designed bridge without corrosion, even with the extra weight of the wearing surface, would have had the capacity to carry legal loads (80,000 pounds without a permit in Pennsylvania).

each leg's capacity. Third, the load rating analysis took the section loss at critical areas of the leg web and distributed the lost material over the entire length of the legs. In doing so, the load rating calculated a new equivalent web thickness for the legs as a whole but failed to account for the potential localized failure due to the section loss and holes. Thus, distributing the section loss over the entire leg length also resulted in an overestimation of the bridge’s capacity.

Correcting any of these assumptions individually would have resulted in a lower estimate for the bridge’s ability to carry loads (that is, its live load capacity). Correcting all three would have reduced the estimate of the bridge’s load posting to less than 3 tons (6,000 pounds), which would have required bridge closure.[89] The NTSB concludes that 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.

Since the bridge collapse, PennDOT has taken steps to ensure that load ratings are correctly calculated. It has added language to Publication 238 to ensure that the load analysis software/methodology is suitable to address the given structure or structural elements and ensure that element conditions such as deterioration, impact damage, or other defects are appropriately assessed and modeled in the load rating analysis (PennDOT 2022a). It is also adding a series of QC questions to its Bridge Management System that address topics including changes to the dead load or live load and any deterioration of the bridge. PennDOT is also creating a *Best Practice Load Rating Manual* (expected to be available in early 2024) and revising its basic and advanced load rating courses to be offered in 2023 and 2024, respectively. The course material will include information on ensuring that conditions such as deterioration, impact damage, and other defects are accounted for in the load rating analysis.

The City, specifically DOMI, has worked with PennDOT to fund additional load rating analyses of City bridges that are covered under the NBI program. As of February 2024, 12 updated analyses had been completed, four were in progress, and several more were scheduled to be completed by the end of the year on bridges covered under the NBI program. Additional load rating analyses performed by an engineering firm and City staff have been completed for 18 local-responsibility vehicular bridges. As a result, all vehicular bridges in the City have a current load

[89] At the time of the collapse, this requirement was in the *MBE* (article 6B.9.1), which was incorporated by reference into the NBIS. Following the 2022 update to the NBIS, this requirement is in regulation at 23 *CFR* 650.313(m).

rating analysis on file. City staff are also performing and updating load rating analyses on 21 local-responsibility pedestrian bridges.

DOMI also worked with PennDOT and the Southwest Pennsylvania Commission to advance $50 million in funding for a rehabilitation project on the Charles Anderson Bridge, which was closed in 2023 based on deterioration and an updated load rating analysis. Updated load rating analyses have led to additional lane restrictions on two other bridges (Swindell Bridge and North Avenue/Brighton Road Bridge), and rehabilitation/replacement plans are being developed for these bridges.

2.4.3.1 Wearing Surface Measurement

Measurements of the wearing surface taken after the bridge collapse showed that the actual asphalt thickness was nearly double the 3 inches specified in the design plan and assumed in the 2014 load rating. With the exception of the 2017 records, the City's paving records (from 1983, 2000, 2005, and 2009) did not contain enough information to determine whether the resurfacing work was performed on the bridge structure, the adjoining roadway, or both. Further, the paving records for these years did not document how much asphalt was removed and replaced. The 2017 records specified that resurfacing was completed on the bridge, and the specifications called for removal of the 3 inches of old surface and replacement with the same amount. As noted, 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. The NTSB concludes that the quality of the City'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. Therefore, the NTSB recommends that the City establish a system to ensure that it maintains paving records indicating how much asphalt wearing surface is removed and how much is subsequently placed during every bridge resurfacing operation.

The actual wearing surface of a bridge affects the estimation of the dead load, which in turn affects the load rating analysis. The FHWA's independent calculation of the load rating postcollapse showed that the double thickness of the asphalt wearing surface would have reduced the bridge's capacity to carry loads; however, the rating would still have been above the legal load limit. The FE analysis results showed that had the bridge legs been free of corrosion, they would have been able to support legal loads in the state of Pennsylvania (up to 80,000 pounds without a permit), even with a 6-inch asphalt wearing surface. However, the corroded southwest leg (B1R) was unable to support these loads with either a 3-inch or a 6-inch wearing surface. Acknowledging the importance of accurate dead load measurements in load rating analyses, PennDOT is requiring that in the next routine inspection, bridge inspectors inspect and measure wearing surfaces to establish the average thickness on bridges that have not been verified since January 1, 2020.[90] PennDOT notes that either coring or driving of a nail into the wearing surface is an acceptable method for measuring the wearing surface thickness.

Collecting a core sample is the most common technique to determine the thickness of asphalt wearing surfaces. However, coring is destructive because it removes material, including possibly cutting through reinforcing steel if cored through a reinforced concrete bridge deck. Coring also opens pathways for water to enter the deck, possibly corroding reinforcing steel and introducing moisture-related damage to the asphalt wearing surface.

Other commonly used methods to determine the thickness of wearing surfaces are to measure the curb height and compare that measurement to design plans or to drive a nail into the surface and measure the visible part of the nail. These methods have drawbacks; there could be differences in thicknesses across the bridge as compared to the curb measurement or the nail could hit a larger piece of aggregate and provide a false measurement.

Non-destructive methods are typically used to assess the thickness of concrete bridge decks, but there is limited technology and guidance on the use of these methods for determining the thickness of asphalt wearing surfaces. A recent report from the FHWA evaluated several different non-destructive methods for assessing concrete bridge decks with different types of overlays including asphalt (FHWA 2021). Although many of these methods have shown promise, ground-penetrating radar (GPR) has been shown to be among the most effective methods for assessing asphalt wearing surface thickness (Edwards and Bell 2012). Typically, GPR antennas are attached to a vehicle or cart, which travels on roadways to collect subsurface information using radio waves (ASTM 2020, AASHTO 2022). The information from these GPR systems can be used to study pavement layer thicknesses, evaluate moisture or density variations, and assess the condition of bridge decks. However, standing water, deicing salts on the surface, and subfreezing temperatures can limit the effectiveness of GPR systems. Additionally, to obtain valid results, equipment needs to be properly calibrated.

Some states are already investing in GPR as a means of moving away from coring to determine the thickness of asphalt wearing surface in state highway projects. For example, the Minnesota Department of Transportation is leading a project (supported by both state and federal funding) to test and advance the use of

[90] This requirement was published in the November 2022 Technical Bulletin: Bridge Safety Inspection and Bridge Maintenance Programs (PennDOT 2022d).

GPR as a method to evaluate asphalt pavements. Protocols and standards for use of the GPR method will also be developed as part of this project.[91]

Understanding the capabilities, limitations, and interpretations of non-destructive technology is important for determining bridge deck and wearing surface thickness. This includes identifying the most effective methods for establishing minimum pavement (or wearing surface) thickness. Guidance is needed on approaches to integrating GPR into common practice and promoting greater use of the technology.

The NTSB concludes that 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. Because non-destructive techniques are effective for different conditions such as types of overlays, state departments of transportation that are considering implementing these technologies as part of their bridge inspection programs would benefit from guidance that encourages the use of non-destructive technologies and that explains how to use them as well as when not to use them. Therefore, the NTSB recommends that the FHWA update its *BIRM* 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. The NTSB also recommends that AASHTO update its *MBE* 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.

2.5 Insufficient Oversight in Detecting and Preventing Bridge Inspection Failures

2.5.1 City of Pittsburgh

The City, as the owner of the Fern Hollow Bridge, is ultimately responsible for its safety. This includes responsibility for inspecting as well as maintaining the bridge. Although aspects of the inspections were faulty, they were completed on schedule via inspectors contracted through PennDOT. Several maintenance and repair recommendations were made in the inspection reports for more than 15 years leading up to the collapse, but the City failed to act on them, resulting in progressive corrosion and deterioration to the point of failure.

[91] For additional information, see Transportation Pooled Fund - Study Detail.

Although the City completed critical maintenance and repair recommendations that were assigned a 0 or 1 priority code, it failed to take action on other recommendations. City records documenting work performed on the bridge were limited for a bridge of this age; those that were available, such as the paving records, provided little information. The NTSB addressed the importance of maintenance in May 2023 when it issued Safety Recommendation H-23-13 asking the FHWA to develop a risk-based, data-driven process for the states to use to identify, prioritize, and perform follow-up actions documented in inspection reports on UWS bridges.

Following the collapse of the bridge, DOMI introduced several changes to its processes to improve management and oversight of City-owned bridges. DOMI's Bridges and Structures Division has added additional personnel, and more positions have been proposed in the 2024 budget. Load rating analyses have been updated, and all vehicular bridges in the City have a current load rating analysis on file. As a result of the updated load rating analyses, which address the deterioration of the bridges, some bridges have been closed or restricted. DOMI is repairing or developing repair plans for these bridges. Additionally, DOMI has increased its bridge maintenance funding and has entered into an agreement for more efficient completion of small bridge repairs.

The changes made by the City via DOMI were in response to many of the issues identified during the investigation of the collapse of the Fern Hollow Bridge. These steps appear to be promising for improved management of bridge assets, but their full effectiveness is not yet known. The NTSB concludes that the postcollapse actions completed by the City 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. Therefore, the NTSB recommends that the City work with PennDOT to evaluate the effectiveness of the changes made by the City 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. Accordingly, the NTSB recommends that PennDOT lead the effort to evaluate and publish a report documenting the effectiveness of the changes made by the City 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.

2.5.2 Pennsylvania Department of Transportation

PennDOT is responsible for ensuring that the bridges in Pennsylvania are inspected in compliance with the NBIS and state regulations. Although the Fern Hollow Bridge was inspected in a timely manner, the investigation of the collapse revealed that the inspections were not performed in compliance with the NBIS. Inspectors failed to perform multiple aspects of the inspections in accordance with the NBIS, including cleaning corrosion before measuring, accurately quantifying remaining material, accurately rating the general bridge superstructure condition, and recommending a structural review of the bridge legs. Additionally, the Fracture-Critical Identification Framing Plan and the Fatigue and Fracture Bridge Inspection Plan failed to identify the legs of the bridge as FCMs, and the load rating for the bridge was not calculated correctly.

Following the bridge collapse, PennDOT was concerned about the safety of other fracture-critical K-frame bridges and bridges with steel-pier bents. PennDOT conducted field examinations of fracture-critical K-frame bridges and file reviews of bridges with steel-pier bents. From these examinations, PennDOT found that better documentation was needed in inspection reports, and it updated the FCM plan for one K-frame bridge that was incorrect.

To improve the quality of inspections, PennDOT made several changes to the bridge inspection guidance provided in Publication 238 and other manuals by adding references to guidance in the *BIRM* and *MBE* as well as supplemental information on load ratings. It improved its QC and QA programs by requiring that bridges with reported condition ratings of 4 or worse be reviewed and that load ratings be conducted on bridges with element CSs of 4. PennDOT developed a verification checklist addressing inspection quality, FCMs, and load ratings. PennDOT has called for a verification of wearing surface thickness during bridge inspections.

The Fern Hollow Bridge collapsed because the City did not complete the maintenance and repair recommendations with priority codes 2 through 5. Although maintenance and repair items coded as priority 0 and 1 were completed, the only priority 2-coded recommendations that were completed were related to repairing the leaking downspouts and re-tensioning the retrofitted structural steel cables. Many other maintenance and repair items, including cleaning debris from the superstructure and reinforcing the stiffeners/repairing the rusted holes, were left unperformed despite the time frame to complete them before the next inspection. In addition, had the bridge legs been correctly identified as FCMs, these maintenance and repair recommendations should have received more urgent priority codes.

In its November 2022 Technical Bulletin, PennDOT created a requirement for inspection organizations to review UWS bridges to ensure that adequate cleaning has been performed during the inspection, priority 2 maintenance needs have been correctly classified, and drainage systems are operating correctly (PennDOT 2022d). PennDOT has added guidance highlighting the need for proper drainage and removal of debris to maintain UWS.

Although the City was the entity responsible for maintaining the bridge, PennDOT was the agency responsible for contracting with the inspectors as well as receiving and reviewing the inspection reports. As such, PennDOT had the opportunity to recognize the noncompliant inspection reports, repeated maintenance and repair recommendations, poor condition ratings of the bridge, and severe condition state ratings of its elements. The FHWA found PennDOT to be conditionally compliant in Metric 12, Inspection Procedures – Quality of Inspections during the PY22 (March 31, 2021, to April 1, 2022) compliance review. As a result, PennDOT was required to develop a PCA. To improve the review of the inspection reports, PennDOT took the corrective action to institute statewide training for QC-level personnel. The NTSB concludes that PennDOT's insufficient oversight of the City's bridge inspection program contributed to the bridge's continued deteriorated condition that led to the collapse. PennDOT has taken steps to improve the inspection process to ensure that bridges in Pennsylvania are inspected in compliance with the NBIS and to identify bridges in need of critical maintenance. It has also provided guidance to improve the maintenance of UWS bridges to extend their life and maintain their safety. However, it is critical to ensure not only that the maintenance and repair recommendations coded as priority 2 through 5 are appropriately coded, but also that action is taken in a timely manner on these recommendations. The NTSB addressed the necessity of completing maintenance in Safety Recommendation H-23-13, issued in May 2023. The NTSB concludes that the postcollapse actions completed by PennDOT—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.

PennDOT cannot compel a bridge owner to perform maintenance, rehabilitation, or replacement of bridges, except through the authority to close a bridge or post a reduced weight limit. However, PennDOT can track and monitor the status of maintenance and repair recommendations from inspection reports and can require an increase in the frequency of inspections related to those recommendations. Recommendations coded with priority codes 2 through 5 are recorded in PennDOT's tracking system but are not tracked in standard reporting documents like those with priority codes 0 and 1. A public, transparent system is needed to monitor completion of maintenance and repair items with priority codes 2 through 5. Publishing aggregate data on maintenance and repair needs would provide a means of monitoring, tracking, and ensuring completion of all recommended actions. Therefore, the NTSB recommends that PennDOT develop and implement a plan to publish yearly aggregate data on bridge maintenance and repair recommendations to monitor completion of these recommendations.

2.5.3 Federal Highway Administration

2.5.3.1 Evaluating Compliance with the National Bridge Inspection Standards

The FHWA monitors the compliance of each state's bridge safety inspection program by evaluating 23 metrics that correspond to the NBIS. To evaluate the metrics, the FHWA examines files, conducts field interviews, analyzes bridge inventory data, and interviews state personnel. NBIS summary reports for PY18 through PY23 showed that over this time period, PennDOT received ratings of Substantially Compliant or Compliant for most years. However, the FHWA assessed PennDOT as Conditionally Compliant in metric 12, Inspection Procedures – Quality of Inspections; metric 13, Inspection Procedures – Load Rating; and metric 19, Inspection Procedures – Complex Bridges. PennDOT has developed PCAs to bring its bridge program into compliance, and the FHWA is monitoring its progress. The field and file reviews conducted by the FHWA to assess whether state departments of transportation are implementing their inspection programs in compliance with the NBIS consist of random samples. It is assumed that the sample of bridges is statistically representative of the overall population of bridges. The FHWA uses a data-driven system to thoroughly investigate issues identified through these samples.

If a problem is identified through the sample of bridges that it reviews, the FHWA can expand its review to address additional, similar bridges to ensure the safety of those bridges for the traveling public. For example, in 2017, based on 2016 NBI data for Mississippi, the FHWA identified 120 bridges with a superstructure or substructure condition rating of 2 (Critical Condition) that were open to traffic. Initially, the FHWA planned to conduct field reviews on a sample of these bridges, but after determining that four of the first six reviewed bridges would be closed or require repair to remain open, the FHWA expanded its review to include more bridges. Ultimately, this effort led to the Governor of Mississippi declaring a state of emergency and the closure of 378 bridges (Ablaza 2018).

There are more than 615,000 bridges listed in the NBI database.[92] The assistant chief bridge engineer for PennDOT estimates that Pennsylvania has more

[92] These include bridges located on public roads—including interstate highways, U.S. highways, and state and county roads—as well as publicly accessible bridges on federal and tribal lands. For additional information, see Bureau of Transportation Statistics: National Bridge Inventory.

than 30,000 bridges, of which 23,257 are reported in the NBI.[93] Analyzing data to assess risk enables the FHWA to target safety issues such as those identified in the Fern Hollow Bridge investigation, including the review of the existing FCM inspection plans recommended in this report. Other issues identified in this investigation that the FHWA could review include (1) evaluating bridges owners' determination of the need to conduct new load ratings of bridges with advanced deterioration, such as those bridges with CS element ratings of 4 for steel elements; and (2) evaluating inspection reports of bridges with advanced deterioration to determine if the assumptions and methods used in the load rating calculations are correct. The NTSB concludes that the FHWA 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. Therefore, the NTSB recommends that the FHWA 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.

2.5.3.2 Sharing of Lessons Learned

The review of the inspections of the Fern Hollow Bridge illustrated several failures of the City's inspection program that contributed to the collapse of the bridge. These failures included inspections that did not meet the guidance provided in the *BIRM* and the *MBE*, such as correctly clearing the rust away, providing measurements of remaining materials, and accurately rating the condition of the bridge. The inaccurate measurements contained in the inspection reports, as well as the use of incorrect assumptions, led to an inaccurate load rating calculation that allowed the bridge to remain open when it should have been closed. The bridge legs, and in particular the transverse tie plates, were not identified as FCMs; therefore, a thorough FCM inspection was not performed on the legs, and the recommendations to repair or replace the transverse stiffeners and web were not assigned the appropriate priority code. However, the maintenance recommendations to repair the section loss and clean the drains, among others, were repeatedly issued, and the City failed to complete the maintenance, resulting in the collapse of the bridge. The NTSB concludes that the Fern Hollow Bridge collapse demonstrates the consequences of failure to complete inspections in accordance with standards, failure to correctly identify FCMs, failure to correctly perform a load rating analysis, and

[93] (a) The 23,257 bridges meet the definition of highway bridge in 23 *CFR* 650, including being greater than 20 feet long. (b) For additional information, see FHWA LTBP [Long-Term Bridge Performance] InfoBridge.

failure of the bridge owner to respond to inspection findings and complete maintenance recommendations in a timely manner.

The FHWA offers several training courses to bridge inspectors.[94] The courses range from introductory-level ("Introduction to Safety Inspection of In-Service Bridges") to higher-level ("Bridge Inspection Techniques for Nonredundant Steel Tension Members") as well as refresher training ("Bridge Inspection Refresher Training"). To be team leaders, inspectors are required by 23 *CFR* 650.309 to complete certain FHWA-approved courses. Therefore, the NTSB recommends that the FHWA incorporate the findings of the Fern Hollow Bridge collapse investigation into its 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 FCMs, and correctly calculate load rating analyses.

[94] For additional information, see National Highway Institute: Course Search.

3 Conclusions

3.1 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

3.2 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.

4 Recommendations

4.1 New Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following new safety recommendations.

To the Federal Highway Administration:

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. (H-24-1)

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. (H-24-2)

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. (H-24-3)

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. (H-24-4)

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. (H-24-5)

To the Pennsylvania Department of Transportation:

Lead the effort 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. (H-24-6)

Develop and implement a plan to publish yearly aggregate data on bridge maintenance and repair recommendations to monitor completion of these recommendations. (H-24-7)

To the City of Pittsburgh:

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. (H-24-8)

Work with the Pennsylvania Department of Transportation to 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. (H-24-9)

To the American Association of State Highway and Transportation Officials:

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. (H-24-10)

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. (H-24-11)

4.2 Previously Issued Recommendation Classified in This Report

The National Transportation Safety Board classifies the following safety recommendation.

To the Federal Highway Administration:

> 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. (H-23-13)

This recommendation is classified Closed—Acceptable Action in section 2.3 of this report.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

JENNIFER HOMENDY
Chair

MICHAEL GRAHAM
Member

THOMAS CHAPMAN
Member

Report Date: February 21, 2024

Appendixes

Appendix A: Investigation

The National Transportation Safety Board (NTSB) was notified of the Pittsburgh, Pennsylvania, bridge collapse on January 28, 2022, and dispatched an investigative team consisting of an investigator in charge, a highway factors investigator, a drone specialist, and a materials engineer (Office of Research and Engineering). The Director of the NTSB Office of Highway Safety was on scene. A project manager was on scene. Chair Jennifer Homendy was the Board Member on scene. Staff from the Chair's office as well as staff from the Office of the Managing Director and the Office of Safety Recommendations and Communications were also on scene.

Party members were the Federal Highway Administration, the Port Authority of Allegheny County (now called Pittsburgh Regional Transit), the Pennsylvania Department of Transportation, and the City of Pittsburgh.

Appendix B: Consolidated Recommendation Information

Title 49 *United States Code* 1117(b) requires the following information on the recommendations in this report.

For each recommendation—

(1) a brief summary of the Board's collection and analysis of the specific accident investigation information most relevant to the recommendation;

(2) a description of the Board's use of external information, including studies, reports, and experts, other than the findings of a specific accident investigation, if any were used to inform or support the recommendation, including a brief summary of the specific safety benefits and other effects identified by each study, report, or expert; and

(3) a brief summary of any examples of actions taken by regulated entities before the publication of the safety recommendation, to the extent such actions are known to the Board, that were consistent with the recommendation.

To the Federal Highway Administration:

H-24-1

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.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in 2.4.2, Fracture-Critical Member Identification. Information supporting (b)(1) and (b)(2) can be found on pages 86–89; (b)(3) is not applicable.

H-24-2

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.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.4.2, Fracture-Critical Member Identification. Information supporting (b)(1) can be found on pages 89–90; (b)(2) and (b)(3) are not applicable.

H-24-3

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.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.4.3.1, Wearing Surface Measurement. Information supporting (b)(1) and (b)(2) can be found on pages 93–94; (b)(3) is not applicable.

H-24-4

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.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.5.3.1, Evaluating Compliance with the National Bridge Inspection Standards. Information supporting (b)(1) and (b)(2) can be found on pages 98–99; (b)(3) is not applicable.

H-24-5

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.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.5.3.2, Sharing of Lessons Learned. Information supporting (b)(1) can be found on pages 99–100; (b)(2) and (b)(3) are not applicable.

To the Pennsylvania Department of Transportation:

H-24-6

Lead the effort 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.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.5.1, City of Pittsburgh. Information supporting (b)(1) can be found on pages 94–95; (b)(2) and (b)(3) are not applicable.

H-24-7

Develop and implement a plan to publish yearly aggregate data on bridge maintenance and repair recommendations to monitor completion of these recommendations.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.5.2, Pennsylvania Department of Transportation. Information supporting (b)(1) and (b)(2) can be found on pages 96–98; (b)(3) is not applicable.

To the City of Pittsburgh:

H-24-8

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.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.4.3.1, Wearing Surface Measurement. Information supporting (b)(1) can be found on page 92; (b)(2) and (b)(3) are not applicable.

H-24-9

Work with the Pennsylvania Department of Transportation to 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.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.5.1, City of Pittsburgh. Information supporting (b)(1) can be found on pages 94–95; (b)(2) and (b)(3) are not applicable.

To the American Association of State Highway and Transportation Officials:

H-24-10

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.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.4.2, Fracture-Critical Member Identification. Information supporting (b)(1) can be found on pages 89–90; (b)(2) and (b)(3) are not applicable.

H-24-11

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.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.4.3.1, Wearing Surface Measurement. Information supporting (b)(1) and (b)(2) can be found on pages 93–94; (b)(3) is not applicable.

Appendix C: Required Federal Qualifications for Bridge Inspection Team Leaders

2004 NBIS with 2009 Revision	2022 NBIS Final Rule
From 23 *CFR* 650.309, "Qualifications of Personnel:"	From 23 *CFR* 650.309, "Qualifications of Personnel:"
There are five ways to qualify as a team leader. A team leader must, at a minimum: (1) Have the qualifications specified in paragraph (a) of this section; or (2) Have five years bridge inspection experience and have successfully completed an FHWA approved comprehensive bridge inspection training course; or (3) Be certified as a Level III or IV Bridge Safety Inspector under the National Society of Professional Engineer's program for National Certification in Engineering Technologies (NICET) and have successfully completed an FHWA approved comprehensive bridge inspection training course; or (4) Have all of the following: (i) A bachelor's degree in engineering from a college or university accredited by or determined as substantially equivalent by the Accreditation Board for Engineering and Technology; (ii) Successfully passed the National Council of Examiners for Engineering and Surveying Fundamentals of Engineering examination; (iii) Two years of bridge inspection experience; and (iv) Successfully completed an FHWA approved comprehensive bridge inspection training course; or (5) Have all of the following: (i) An associate's degree in engineering or engineering technology from a college or university accredited by or determined as substantially equivalent by the Accreditation Board for Engineering and Technology; (ii) Four years of bridge inspection experience; and (iii) Successfully completed an FHWA approved comprehensive bridge inspection training course.	A team leader must, at a minimum: (1) Meet one of the four qualifications listed in paragraphs (b)(1)(i) through (iv) of this section: (i) Be a registered Professional Engineer and have 6 months of bridge inspection experience; (ii) Have 5 years of bridge inspection experience; (iii) Have all of the following: (A) A bachelor's degree in engineering or engineering technology from a college or university accredited by or determined as substantially equivalent by the Accreditation Board for Engineering and Technology; and (B) Successfully passed the National Council of Examiners for Engineering and Surveying Fundamentals of Engineering examination; and (C) Two (2) years of bridge inspection experience; or (iv) Have all of the following: (A) An associate's degree in engineering or engineering technology from a college or university accredited by or determined as substantially equivalent by the Accreditation Board for Engineering and Technology; and (B) Four (4) years of bridge inspection experience; (2) Complete an FHWA-approved comprehensive bridge inspection training course as described in paragraph (h) of this section and score 70 percent or greater on an end-of-course assessment (completion of FHWA-approved comprehensive bridge inspection training under FHWA regulations in this subpart in effect before June 6, 2022, satisfies the intent of the requirement in this paragraph (b)); (3) Complete a cumulative total of 18 hours of FHWA-approved bridge inspection refresher training over each 60 month period; (4) Provide documentation supporting the satisfaction of paragraphs (b)(1) through (3) of this section to the program manager of each State transportation department, Federal agency, or Tribal government for which they are performing bridge inspections; and (5) Satisfy the requirements of this paragraph (b) within 24 months from June 6, 2022, if serving as a

2004 NBIS with 2009 Revision	2022 NBIS Final Rule
	team leader who was qualified under prior FHWA regulations in this subpart. Team leaders on NSTM inspections must, at a minimum: (1) Meet the requirements in paragraph (b) of this section; (2) Complete an FHWA-approved training course on the inspection of NSTMs as defined in paragraph (h) of this section and score 70 percent or greater on an end-of-course assessment (completion of FHWA-approved NSTM inspection training prior to June 6, 2022, satisfies the intent of the requirement in this paragraph (c)); and (3) Satisfy the requirements of this paragraph (c) within 24 months from June 6, 2022.

Source: National Bridge Inspection Standards, Side Side-by-Side Comparison between Previous Regulation and Final Rule

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