May 3, 2023 HIR-23-07

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

1. Introduction

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

2. Background and Analysis

2.1 Collapse Summary and Bridge Description

On Friday, January 28, 2022, about 6:40 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.[1] As a result, the 447-foot-long bridge fell about 100 feet into the park below (see figure 1). At the time of the collapse, a 2013 New Flyer articulated 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 following the collapse and came to rest on its roof on the ground below. As a result of the collapse, two vehicle

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

occupants sustained serious injuries, two sustained minor injuries, four were uninjured, and the injury status of one is unknown.[2]

Figure 1. View of collapsed Fern Hollow Bridge from the east.

In the area of the collapse, Forbes Avenue was a four-lane, non-divided roadway consisting of two travel lanes each in the eastbound and westbound directions. Sidewalks flanked the travel lanes on both sides. The posted speed limit on the bridge was 35 mph, and the posted weight limit was 26 tons. At the time of the collapse, it was snowing, and some snow had accumulated on the roadway and bridge surfaces.

[2] (a) Although 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, in part, 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. (b) Injury levels are based on the City of Pittsburgh Bureau of Police Investigative Report for the collapse, which may not reflect complete medical information.

The bridge was constructed from uncoated weathering steel plate in a three-span, continuous rigid "K" frame structure with two welded steel girders (see figure 2).[3] The ends of the structure rested on reinforced concrete caps on stone masonry abutments. Each girder was additionally supported by two inclined, welded steel legs, also made of uncoated weathering steel plate, which rested atop reinforced concrete thrust blocks. Bent 1 comprised the two legs and thrust blocks on the west (or near) side of the bridge and associated cross-bracing between these legs. Similarly, Bent 2 comprised the two legs and thrust blocks on the east (or far) side and associated cross-bracing between these legs.[4] Thus, there were four legs on this bridge, which can be referred to as the northwest, southwest, northeast, and southeast legs.

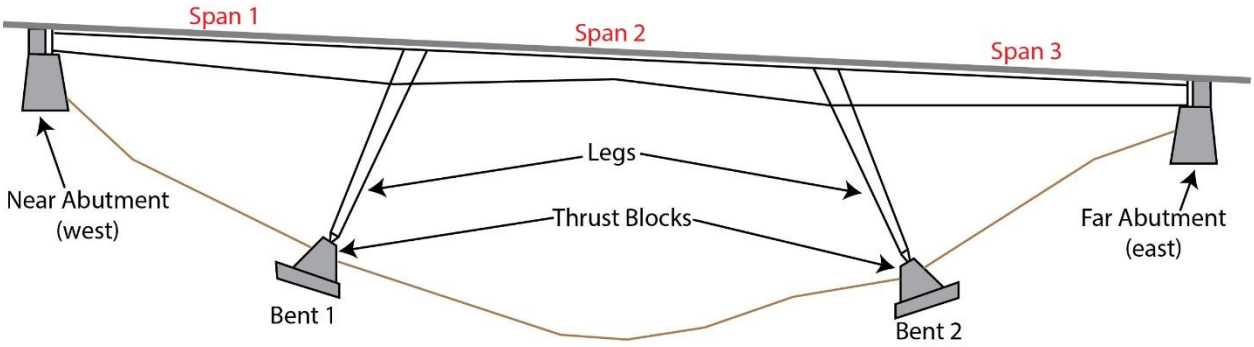

Figure 2. Simplified side view (elevation) of K frame structure. Bents 1 and 2 were composed of two legs each. Only the southwest and southeast legs are visible in this diagram.

The thickness of the web plates used for the main girder and legs required the use of longitudinal and transverse stiffeners to suppress buckling (see figure 3).[5]

[3] *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.

[4] The inspection reports for the Fern Hollow Bridge refer to the west side as "near" and the east side as "far."

[5] The girders and legs were constructed as I-shapes with two flanges and a web plate. The *web plate* is a steel plate that connects the two flanges and is oriented perpendicular to both flanges. *Flanges* are steel plates that resist bending. *Buckling* is a failure mode where a beam deforms sideways under compressive loads.

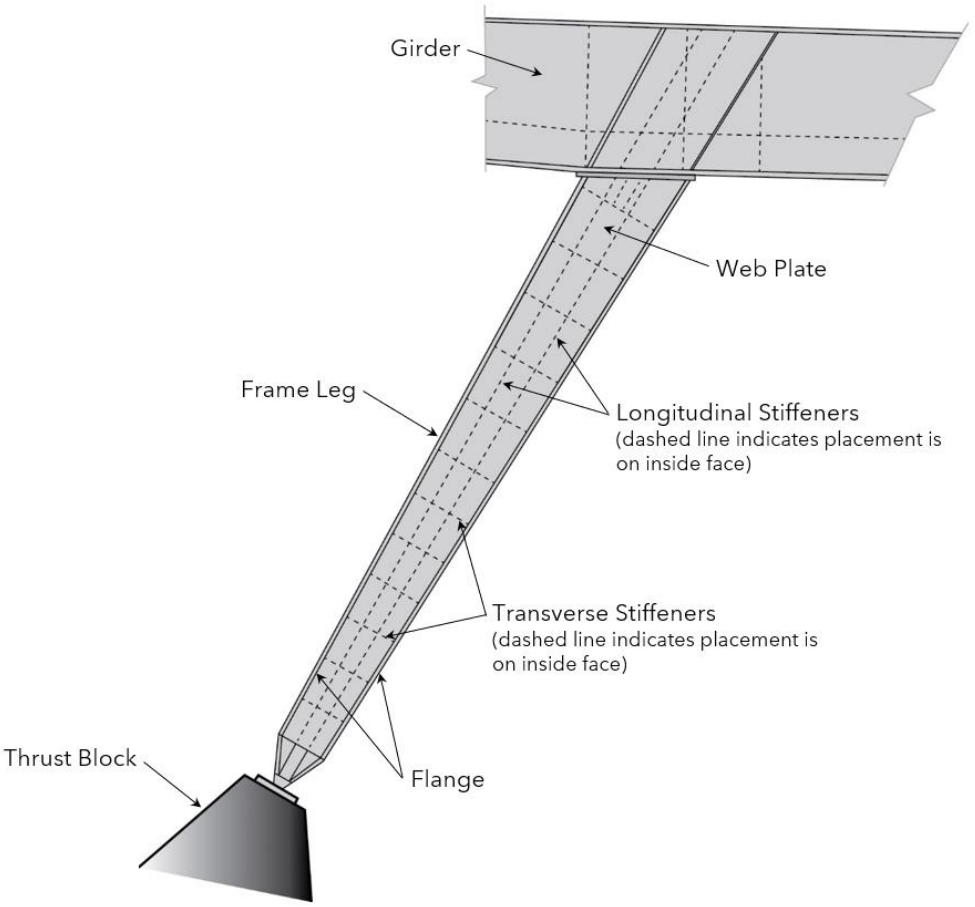

Figure 3. Elevation view of Fern Hollow Bridge leg and segment of main girder, shown from the outside. (Source: FHWA; modified by NTSB)

Uncoated weathering steel is designed for use in environments that experience weather cycles with phases of wetting and drying. The dry periods are critical to the steel forming a protective oxide coating, or patina, that resists corrosion over time.[6] The presence of ponding water and debris buildup can trap water 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 uncoated weathering steel. Additionally, these buildups can contain residual roadway salts that further contribute to corrosion. FHWA Technical Advisory 5140.22, *Uncoated Weathering Steel in Structures*, provides engineers with guidelines for the use and maintenance of

[6] (a) National Steel Bridge Alliance. *Uncoated Weathering Steel Reference Guide*. Chicago, IL: American Institute of Steel Construction, 2022. (b) Hopwood, T., S. Palle, B.W. Meade, and R. Younce. "Evaluation of the Use of Painted and Unpainted Weathering Steel on Bridges." *Kentucky Transportation Center Research Report 1562*. June 2016.

uncoated weathering steel for bridge structures.[7] These guidelines include drainage information and maintenance actions specifying the need to remove debris and ensure that drainage is adequate to allow the uncoated weathering steel material to cycle between wet and dry.

2.2 Fern Hollow Bridge Investigation

The NTSB found extensive corrosion damage and deterioration of the Fern Hollow Bridge legs during the on-scene examination of the collapsed bridge. We also reviewed the National Bridge Inspection Standards inspection reports for the 17 years before the collapse.[8] Starting in 2005, each of these inspection reports documented corrosion damage and deterioration of the bridge legs (see figure 4), including the most recent inspection report in September 2021, 4 months before the collapse (see figure 5).

Figure 4. Section loss on lower bracing of northwest bridge leg (left image) and corrosion damage on southwest bridge leg below bracing (right image). (Source: September 2005 inspection report)

[7] FHWA. Technical Advisory: Uncoated Weathering Steel in Structures. Technical Advisory 5140.22. October 3, 1989; updated June 27, 2017.

[8] (a) The City of Pittsburgh owns the Fern Hollow Bridge and is required to inspect it in accordance with the National Bridge Inspection Standards. However, the Pennsylvania Department of Transportation (PennDOT) has the responsibility to ensure that all bridges in the state that are subject to the National Bridge Inspection Standards, including local bridges, are compliant with these standards. The inspection reports were completed as part of PennDOT's inspection program under a master contract to ensure that bridges are inspected in compliance with 23 *CFR* 650.311. (b) Routine inspections are conducted at intervals not to exceed 24 months. Certain bridges may, based on condition or other risk factors, require inspection at an interval less than 24 months based on criteria developed by the state Department of Transportation (23 *CFR* 650.311). Between 2005 and 2021, nine routine and five interim inspections were conducted on the Fern Hollow Bridge.

Figure 5. Corrosion damage including areas of 100% section loss on southwest bridge leg near connection to reinforced concrete thrust blocks (circled in yellow in photograph on left and shown in closer view in photograph on right). (Source: September 2021 inspection report)

The NTSB Materials Laboratory conducted three-dimensional laser scanning of the lower portions of the bridge legs to examine the extent of the section loss on the structural elements due to corrosion damage. Figure 6 shows an image of the remaining section found on the bottom of the northwest leg postcollapse.[9]

[9] See the NTSB Materials Laboratory three-dimensional scanning factual report in the docket for additional information.

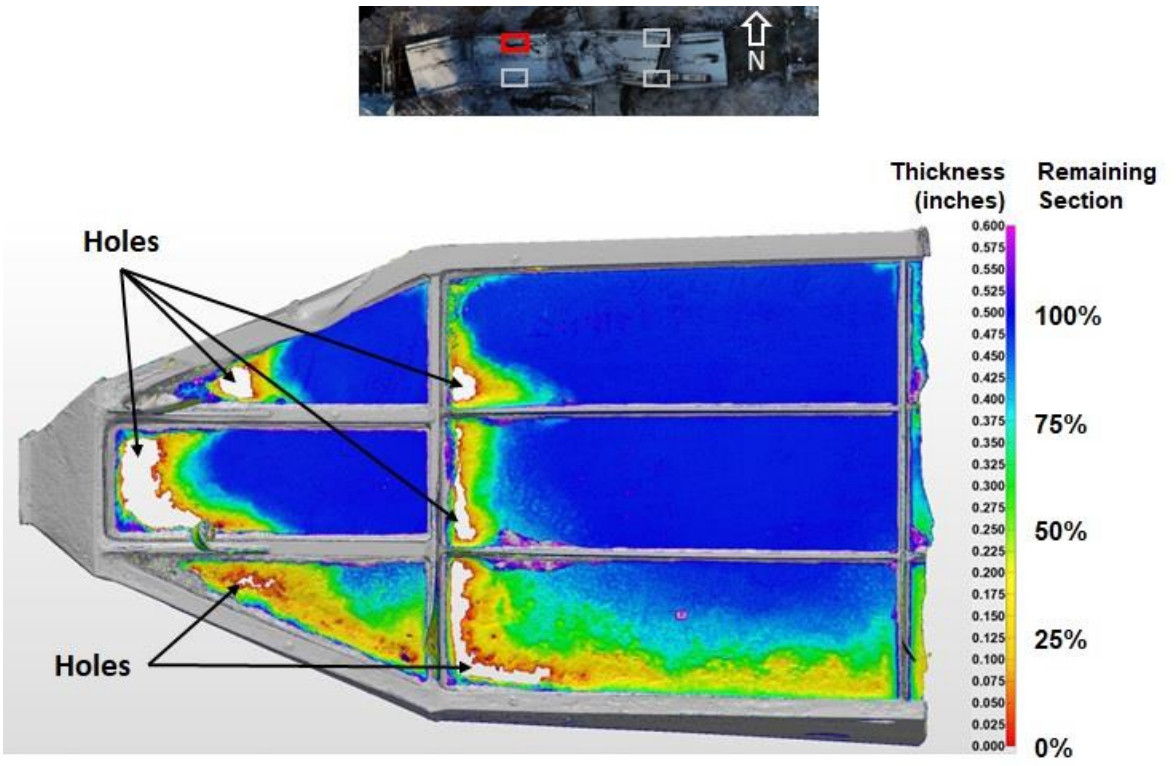

Figure 6. Three-dimensional laser scan image showing remaining section on bottom of northwest leg postcollapse. Per the design plan, the nominal thickness of the leg web plate was 0.5 inches; the blue in the figure indicates areas of the leg web that met the design plan, and the yellow indicates areas that were about 25% of the nominal thickness. The red square in the image above the figure shows the northwest leg's position in the bridge structure.

Further, drainage issues, including drains blocked by debris, dirt, and plant material, were documented in the inspection reports, both in writing and in photographs (see figure 7). The blocked drains led to improper drainage, allowing water and other contaminants, such as deicing salts, to drain onto areas of the bridge not designed for water flow, resulting in evidence of active leakage on steel surfaces such as the bridge legs. In 2009, a rehabilitation project was conducted to replace the downspouts, which required all bridge drains to be cleaned. The 2009 inspection report reflects that this work was completed and described the drains as being clear. However, the 2011 inspection report noted that some of the drains had become clogged again. Clogged drains and the need for associated maintenance work were continually identified in the inspection reports between 2011 and 2021.

Figure 7. Blocked drains on Fern Hollow Bridge. (Source: September 2021 inspection report)

As noted above, our examination of the bridge as well as the inspection reports found critical structural components on the Fern Hollow Bridge, including portions of the welded steel legs, with extensive corrosion damage, deterioration, and section loss in the areas with debris and improper drainage. The steel section loss was severe to the point that there were holes in numerous structural elements on all four legs, including the longitudinal and transverse stiffeners (for example, refer to figures 4 and 5). The NTSB concludes that the legs of the Fern Hollow Bridge experienced significant deterioration and section loss that were documented in inspection reports. The deterioration and section loss resulted from the continual accumulation of water and debris, which prevented the development of the protective patina that would resist such corrosion on uncoated weathering steel.

2.3 Examinations of Other Pennsylvania Bridges

NTSB investigators and FHWA engineers conducted limited examinations of ten similar steel-frame bridges in Pennsylvania's bridge inventory, some of which were constructed using uncoated weathering steel. Although not as severe as on the Fern Hollow Bridge, the examinations revealed maintenance problems that allowed the buildup of debris on and around bridge legs, improper drainage, and associated corrosion (see figure 8). These conditions were also documented in the inspection reports for these bridges. The NTSB concludes that the limited examinations of other Pennsylvania bridges revealed that the problem of incomplete maintenance—where maintenance was identified as needed in inspection reports but not completed—was not unique to the Fern Hollow Bridge.

Figure 8. Photographs of built-up debris, lack of drainage, and associated corrosion on Fahy Bridge in Bethlehem, Pennsylvania (left); McCallum Street Bridge in Philadelphia, Pennsylvania (middle); and Shenango Road Bridge in Darlington, Pennsylvania (right).

On November 14, 2022, PennDOT issued a technical bulletin that modified Pennsylvania's bridge safety inspection and maintenance programs in response to the Fern Hollow Bridge collapse.[10] Specific to the safety issue identified in this report (that is, lack of maintenance to prevent the water and debris accumulation contributing to corrosion), the technical bulletin establishes a statewide review of weathering steel bridges with a purposeful focus on weathering steel components and provides a timeline for completion of maintenance work identified through inspection reports.[11] The technical bulletin also acknowledges the omission of important information in the state's *Bridge Maintenance Manual* regarding the unique characteristics of uncoated weathering steel and the special maintenance needs for uncoated weathering steel bridges. The technical bulletin lists new information to be incorporated into the maintenance manual and stresses the need for enhanced attention to maintenance items such as controlling roadway drainage; regularly removing dirt, debris, and other deposits that trap moisture; and regularly removing vegetation that can prevent drying of wet steel surfaces.

More than 10,000 bridges in the United States have been built using uncoated weathering steel.[12] If used under appropriate conditions and properly maintained, weathering steel bridges can last decades.[13] However, as with any other steel, failure to properly maintain uncoated weathering steel can lead to corrosion damage,

[10] PennDOT. Technical Bulletin: Bridge Safety Inspection and Bridge Maintenance Programs. November 14, 2022.

[11] Some uncoated weathering steel bridges have had portions of the steel coated, or painted, to provide a protective surface. The technical bulletin addresses specific information for both coated and uncoated weathering steel.

[12] McConnell, J., H.W. Shenton, D. Mertz, and D. Kaur. "Performance of Uncoated Weathering Steel Highway Bridges Throughout the United States." *Transportation Research Record*, 2406, no. 1: 61-67. January 1, 2014.

[13] National Steel Bridge Alliance. *Uncoated Weathering Steel Reference Guide*. 2022.

deterioration, and section loss in critical components, thus reducing the safety and service life of the bridge.

Although the NTSB found evidence of water and debris accumulation and resultant corrosion on other bridges in Pennsylvania, the NTSB does not know how widespread the issue is and has no evidence to suggest that the degree of corrosion found on the Fern Hollow Bridge exists on other bridges. Further, maintenance actions were identified in the yearly inspection reports for the Fern Hollow Bridge but were not performed during the 11 years leading up to the bridge collapse. Our investigation of why the maintenance activities prescribed by the inspection reports were not completed, as well as the effects of the corrosion on the bridge's load rating, is ongoing. Although Pennsylvania has established a statewide review of weathering steel bridges and associated maintenance actions, we cannot dismiss the possibility that there are other uncoated weathering steel bridges throughout the country that have not been maintained properly and have enabled the accumulation of water and debris, thereby preventing the development of the weathering steel patina.

The NTSB concludes that, because of the potential for corrosion and deterioration associated with lack of proper maintenance, it is critical that bridge owners nationwide ensure that follow-up actions addressing the accumulation of water and debris on bridges with weathering steel components have been completed. Although the FHWA does not have the authority to require that inspection-identified maintenance is performed, the FHWA can require states and other entities to ensure that their bridges have accurate capacity ratings and are safe for the traveling public. Proper maintenance is critical to bridge safety.

In summary, our investigation of the Fern Hollow Bridge revealed extensive corrosion and deterioration of the bridge's uncoated weathering steel components. Maintenance activities to address these issues were called for in numerous inspection reports but were not completed. Our examinations of other Pennsylvania bridges showed similar corrosion and deterioration problems associated with maintenance activities that were identified but not completed. Due to the safety risk that these issues pose, as well as the likelihood that they exist on other bridges throughout the country, there is a need for bridge owners nationwide to ensure that documented follow-up actions have been performed on their bridges with uncoated weathering steel components.

The FHWA is the federal agency that provides national policy and technical guidance to support the safety and oversight of bridges. Therefore, the NTSB recommends that 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.

The actions described in this recommendation, if taken, will address the safety issue regarding the maintenance of uncoated weathering steel bridges identified thus far in this investigation. We note, however, that removing debris and ensuring proper drainage of these bridges is only one aspect of ensuring the safety of uncoated weathering steel bridges.

The NTSB also notes that the need for these actions is based on preliminary findings during our ongoing investigation. Additional actions may be recommended as the investigation proceeds.

3. Findings

1. The legs of the Fern Hollow Bridge experienced significant deterioration and section loss that were documented in inspection reports. The deterioration and section loss resulted from the continual accumulation of water and debris, which prevented the development of the protective patina that would resist such corrosion on uncoated weathering steel.

2. The limited examinations of other Pennsylvania bridges revealed that the problem of incomplete maintenance—where maintenance was identified as needed in inspection reports but not completed—was not unique to the Fern Hollow Bridge.

3. Because of the potential for corrosion and deterioration associated with lack of proper maintenance, it is critical that bridge owners nationwide ensure that follow-up actions addressing the accumulation of water and debris on bridges with weathering steel components have been completed.

4. 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)

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For more detailed background information on this report, visit the NTSB investigations website and search for NTSB accident ID HWY22MH003. Recent publications are available in their entirety on the NTSB website. Other information about available publications also may be obtained from the website or by contacting—

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