United States Government Accountability Office

Report to Congressional Committees

September 2021

HIGHWAY BRIDGES

Federal Highway Administration Could Better Assist States with Information on Corrosion Practices

A Century of Non-Partisan Fact-Based Work

GAO-21-104249

GAO@100

Highlights

Highlights of GAO-21-104249, a report to congressional committees

Why GAO Did This Study

In 2021, U.S. bridges, including those on the NHS, were estimated to need billions of dollars in repairs, including efforts to mitigate the effects of corrosion. House Report 116-106 included a provision for GAO to review the status of states' bridge corrosion-control planning. This report examines: (1) trends in the condition of bridges on the NHS and what is known about how corrosion affects bridge condition, (2) practices states use to address corrosion on NHS bridges and how selected states prioritize efforts to address corrosion, and (3) how FHWA assists states in addressing bridge corrosion.

GAO reviewed applicable statutes, regulations, guidance, and studies related to corrosion prevention and management, and analyzed data on NHS bridges. GAO selected five states—Florida, Illinois, Kansas, Rhode Island, and Wyoming—based on factors, such as the percentage of bridge deck area in good and poor condition and geographic diversity. Finally, GAO interviewed FHWA, state transportation, and various association officials and assessed FHWA's actions against internal controls for using quality information.

What GAO Recommends

GAO is recommending that FHWA's ongoing bridge preservation efforts include activities that focus on addressing the challenges states face with determining the circumstances under which specific corrosion practices and materials are most effective. DOT agreed with our recommendation and provided technical comments, which we incorporated as appropriate.

View GAO-21-104249. For more information, contact Andrew Von Ah at (202) 512-2834 or vonaha@gao.gov.

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HIGHWAY BRIDGES

Federal Highway Administration Could Better Assist States with Information on Corrosion Practices

What GAO Found

According to the Federal Highway Administration's (FHWA) database of information on bridges' condition, the percentage of deck area, a measure that accounts for the size of a bridge, for National Highway System (NHS) bridges in poor condition has decreased since 2012. However, since 2016, the percentage of deck area for NHS bridges in good condition has also decreased, while the percentage of deck area for bridges in fair condition has increased. Although these data do not indicate the extent to which corrosion affects bridges' condition, studies GAO reviewed and stakeholders GAO spoke with—including FHWA, five selected states, and six associations—indicate a significant relationship between corrosion and bridge condition. (See figure.)

Examples of Bridge Corrosion

Sources: Rhode Island Department of Transportation (left), Wyoming Department of Transportation (middle), and Kansas Department of Transportation (right). | GAO-21-104249

State practices to prevent and manage corrosion vary based on environmental factors and bridge condition. For example, states exposed to sea water and deicing chemicals may clean bridges to remove materials that could accelerate corrosion. Four of the five selected states prioritized rehabilitating and replacing poor condition bridges, while the fifth state said it took steps to address corrosion to preserve and maintain bridges in good and fair condition. States are transitioning to asset management practices that emphasize bridge preservation strategies. However, officials from the selected states said limited information about specific corrosion practices' effectiveness is a challenge to implementing asset management practices. For example, officials from some selected states said they use sealant on bridge decks to prevent corrosion while officials from another said they do not because they do not know how effective it is.

FHWA, within the Department of Transportation, helps states address corrosion through research and technical assistance. However, FHWA efforts have generally focused on overall bridge condition and may not meet states' needs to determine the circumstances in which to use specific practices. For example, FHWA's *Bridge Preservation Guide* identifies practices that can be part of a bridge preservation approach but does not indicate under what circumstances they are most effective. Although FHWA does not endorse specific practices, officials recognize their role in helping states make well-informed decisions regarding bridge corrosion. As states continue transitioning to an asset management approach, providing information about the circumstances under which different corrosion practices are most effective could help states make best use of their resources.

Contents

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
COVID-19	Coronavirus Disease 2019
DOT	U.S. Department of Transportation
FAST Act	Fixing America's Surface Transportation Act
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
KDOT	Kansas Department of Transportation
IDOT	Illinois Department of Transportation
MAP-21	Moving Ahead for Progress in the 21st Century Act
NHPP	National Highway Performance Program
NHS	National Highway System
RIDOT	Rhode Island Department of Transportation
state DOT	state department of transportation
WYDOT	Wyoming Department of Transportation

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September 28, 2021

The Honorable Brian Schatz
Chairman
The Honorable Susan Collins
Ranking Member
Subcommittee on Transportation, Housing and Urban Development, and Related Agencies
Committee on Appropriations
United States Senate

The Honorable David E. Price
Chairman
The Honorable Mario Diaz-Balart
Ranking Member
Subcommittee on Transportation, and Housing and Urban Development, and Related Agencies
Committee on Appropriations
House of Representatives

In 2021, the American Society of Civil Engineers estimated that nearly 231,000 U.S. bridges were in need of $125 billion in repairs. This estimate includes bridges along the 220,000 miles of the National Highway System (NHS), a network of roadways considered important to the nation's economy, defense, and mobility. In 2020, according to Federal Highway Administration's (FHWA) data, there were about 146,000 bridges on the NHS. Numerous factors play a role in the deterioration of bridges, such as the age of the bridge and how heavily it is used. However, the role corrosion plays in the deterioration of bridges is of particular concern, as about one-third of all bridges in the U.S. are made of steel, and other bridges may have steel components that are susceptible to corrosion. In 2020, FHWA reported that the National Association of Corrosion Engineers estimated the annual direct cost of corrosion for highway bridges was $13.6 billion in 2013.[1]

Under the Moving Ahead for Progress in the 21st Century Act (MAP-21) and the Fixing America's Surface Transportation Act (FAST Act)—the two

[1]Federal Highway Administration, *Detecting Bridge Corrosion with a Robotic Magnetic-based NDE System*, Hoda Azari and Sadegh Shams, FHWA-HRT-21-001 (Washington, D.C.: Autumn 2020).

most recent surface transportation reauthorization acts—FHWA, within the U.S. Department of Transportation (DOT)—provided an average of $40 billion in formula funding annually for fiscal years 2013 through 2020 to build and maintain the nation's roadway and bridge infrastructure, including infrastructure on the NHS.[2] These funds are provided through federal-aid highway program grants to states and localities, which own and maintain most of the nation's highways and bridges. As a part of their maintenance activities, state departments of transportation (state DOT) are required to inspect all highway bridges on public roads within their boundaries in accordance with federal standards, known as the National Bridge Inspection Standards,[3] and compile and submit the information related to these inspections and bridge conditions into the National Bridge Inventory, a database maintained by FHWA.[4]

Recognizing that corrosion is a leading cause of bridge failure, the explanatory statement accompanying the Further Consolidated Appropriations Act, 2020, included a provision for us to report on the status of bridge corrosion control planning by state DOTs.[5] This report examines:

- trends in the condition of bridges on the NHS and what is known about how corrosion affects bridge condition;
- practices states use to address corrosion on NHS bridges and how selected states are prioritizing efforts to address corrosion; and
- how FHWA assists states in addressing corrosion on NHS bridges.

In addressing these objectives, we focused on the condition of NHS bridges, as the NHS accounts for the majority of annual vehicle miles

[2]MAP-21, Pub L. No. 112-141, § 1101(a)(1), 126 Stat. 405, 414 (2012); FAST Act, Pub L. No 114-94, § 1101(a)(1), 129 Stat. 1312, 1322 (2015).

[3]The National Bridge Inspection Standards are located in 23 C.F.R. Part 650, Subpart C.

[4]Because states are required to enter bridge information and inspection data into the National Bridge Inventory for all highway bridges on public roads, the National Bridge Inventory contains data on bridges located both on and off the NHS.

[5]Pub. L. No. 116-94, 133 Stat. 2534 (2019); Staff of H. Comm. on Appropriations, 116th Cong., Explanatory Statement on Further Consolidated Appropriations Act, 2020, at 1167 (Comm. Print 2020) (incorporating H.R. Rep. No. 116-106, at 32 (2019)). In December 2020, we provided an interim briefing to the Senate and House Appropriations Committees to meet our reporting date.

traveled and chose calendar years 2012 through 2020 for our analysis to generally coincide with the fiscal years covered by MAP-21 and the FAST Act. We also obtained information from five selected states on practices they use to address corrosion on NHS bridges based on factors such as the condition of bridges and bridge deck area in the state and geographic diversity. We selected these states—Florida, Illinois, Kansas, Rhode Island, and Wyoming—based on such factors as:

- having the highest number and percentage of bridges and bridge deck area in good and poor condition, according to National Bridge Inventory data;[6]
- having geographic diversity, to account for environmental conditions that can affect bridge condition; and
- whether a state had been required to set aside federal funds for eligible bridge projects.[7]

To determine trends in the condition of NHS bridges, we analyzed data from the National Bridge Inventory from 2012 through 2020 to identify such things as the number of bridges, square feet of deck area for bridges in good, fair, and poor condition, as well as the average age of NHS bridges.[8] Additionally, for poor condition bridges in our selected states, we analyzed element-level data in the National Bridge Inventory for 2019 to obtain additional information on elements that had quantities

[6]In selecting states, we analyzed National Bridge Inventory data from 2012 through 2019, the most recently available data at the time of our selection. We selected two states that were among those with the highest number of NHS bridges and highest percentages of bridge deck area in good condition and three states that were among the highest number of bridges and highest percentages of bridge deck area in poor condition.

[7]If FHWA determines that for 3 consecutive years, more than 10 percent of the total deck area of a state's NHS bridges is located on NHS bridges classified as in poor condition, then the state must set aside a certain amount of National Highway Performance Program funds each fiscal year thereafter for use on eligible NHS bridge projects, until the percentage falls below 10 percent. 23 U.S.C. § 119(f)(2); 23 C.F.R. §§ 490.411, 490.413.

[8]Deck area is a measure that accounts for the size of bridges. We include culverts (structures with fill over them) in measurements of total deck area.

in poor or severe condition.[9] To assess the reliability of these data, we reviewed the National Bridge Inventory coding guide and related documentation,[10] discussed these data with FHWA officials, and conducted electronic testing of these data. We found these data to be sufficiently reliable for our purposes of describing bridge condition on NHS bridges and for describing the elements that had quantities in poor or severe condition. We also reviewed selected studies, described below, and interviewed FHWA headquarters and Division Office officials as well as selected state DOT officials about the role corrosion plays in bridge condition.

In addition, to determine what is known about how corrosion affects NHS bridges' condition, we analyzed available defect data on bridge corrosion from three of the five selected states that collect these data in their bridge management systems, which are computer software programs that recommend optimized maintenance and repair strategies to make the best use of federal and other funds.[11] Defect data have more detailed information about the condition of certain bridge elements and include specific information about corrosion on those elements. We assessed the reliability of selected states' defect data by reviewing the American Association of State Highway and Transportation Officials' (AASHTO)

[9]FHWA generally defines a bridge as consisting of three major components: superstructure, substructure, and deck. Bridge components, in turn, are formed from the individual members of a bridge, known as "elements." Although we focused on bridges classified as in poor condition, there is not a direct correlation between element-level data that rates quantities of elements in a particular condition state and the overall condition classification of a bridge. At the time of our study, FHWA had element-level data for all NHS bridges for one year, 2019. According to FHWA officials, FHWA has been reviewing the submitted data against a standard set of error checks and plans to conduct file reviews of element-level inspections for a sample of bridges to verify the quality of this data starting in June 2021. FHWA plans to conduct field inspections but has delayed them due to Coronavirus Disease 2019 (COVID-19) travel restrictions and officials were unsure when they would begin.

[10]FHWA, *Recording and Coding Guide for the Structure and Inventory and Appraisal of the Nation's Bridges*, Report No. FHWA-PD-96-001 (Washington, D.C., December 1995).

[11]For the states that collect defect data, two states provided data as of June 30, 2020. The other state provided data as of October 27, 2020 because its system could not go back to June 2020. One of the two states that do not collect defect data was able to query its system to provide data on corrosion. According to officials in the other state, they do not collect data on corrosion but they do document it in inspection reports. FHWA does not require states to collect these data.

Manual for Bridge Element Inspection[12] and applicable state documents. We also spoke with selected state DOT officials about data reliability and limitations and found these data to be sufficiently reliable for our purposes of describing the effect of corrosion on bridge conditions in selected states.

To determine the practices states use to address corrosion, we reviewed 87 relevant academic, government, and industry studies from 2010 to 2020 to identify practices and techniques used in the U.S. to address corrosion on bridges.[13] We also collected and analyzed information from the five selected states to identify their practices for addressing corrosion on bridges and challenges to addressing corrosion on bridges. We also conducted semi-structured interviews with FHWA division office and state DOT officials from selected states about their practices to prevent and manage bridge corrosion. Information we collected and analyzed from these states include bridge inspection reports, states' transportation-asset management plans, and information about their corrosion mitigation practices. The information gathered from the selected states cannot be generalized to all states; however, state officials provided insight into the types of practices states may use to prevent and manage corrosion.

Finally, we interviewed industry associations familiar with bridge design, inspection and maintenance, as well as corrosion and its effect on bridges, including AASHTO, the Association for Materials Protection and Performance, the American Society of Civil Engineers, the International Union of Painters and Allied Trades, the American Road and Transportation Builders Association, and the International Bridge, Tunnel, and Turnpike Association to discuss bridge corrosion mitigation practices.[14] Most of these interviews also included current and former representatives from various state DOTs. (We include additional

[12]AASHTO, *Manual for Bridge Element Inspection, Second Edition* (Washington, D.C., 2019)

[13]We conducted a literature search to identify studies published beginning in 2010 about bridge corrosion and condition in the Transportation Research Board's database and ProQuest, Dialog, EBSCO, and Scopus databases. We conducted the searches between July and October 2020. We identified 231 studies that were relevant for our review and reviewed 87 of these for our study. We also identified other studies about bridge corrosion, for example, through interviews with FHWA officials as well as reviews of FHWA's website and the websites of universities that conduct research on practices to address corrosion for state DOTs.

[14]The Society for Protective Coatings and the National Association of Corrosion Engineers are now the Association for Materials Protection and Performance.

information about corrosion mitigation practices used in the selected states in app. I.)

To determine how FHWA assists states in addressing bridge corrosion, we reviewed applicable statutes and FHWA regulations, policies, procedures, reports, and similar material to identify the types of assistance FHWA provides to states regarding bridge preservation and corrosion management, and interviewed FHWA's Office of Bridges and Structures, the Turner-Fairbank Highway Research Center, and FHWA Division Office officials for the selected states about the assistance they provide regarding bridge corrosion prevention and management. We also interviewed selected state DOT and industry association officials to obtain their views on FHWA's assistance to states. We compared FHWA's actions to *Standards for Internal Control in the Federal Government* to assess whether the agency communicated quality information to achieve its objectives.[15]

We conducted this performance audit from April 2020 to September 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Federal and State Roles and Responsibilities for NHS Bridges

FHWA is the federal agency charged with oversight of the condition of the nation's bridges and is generally responsible for ensuring that infrastructure on the NHS—including bridges—continues to be safe for public travel. FHWA administers the federal-aid highway program, an umbrella term encompassing a collection of grant programs, including the National Highway Performance Program (NHPP), which provides funding to states for bridge projects and activities, including construction, replacement, rehabilitation, preservation, and protection.[16] FHWA oversees the federal-aid highway program primarily through its Division

[15]GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: September 2014).

[16]23 U.S.C §119.

Offices, which assist states by reviewing state construction specifications to ensure they meet the standards for federally funded construction projects. Division Offices also conduct regular reviews of state bridge inspection programs. These reviews ensure that bridge deficiencies, including corrosion, are properly observed and recorded.[17]

State DOTs are responsible for managing their bridge programs and select and prioritize which infrastructure projects, including bridge projects, in their state will receive federal funding. In addition, state DOTs are responsible for ensuring highway bridges on public roads in their states are inspected according to the National Bridge Inspection Standards, unless the bridge is owned by a federal agency or tribal government.[18]

NHS Bridges and Corrosion

FHWA generally defines a bridge as consisting of three major components: superstructure, substructure, and deck.[19] Bridge components, in turn, are formed from the individual members of a bridge, known as "elements."[20] Examples of elements that may include steel and thus are subject to corrosion include girders (part of the superstructure),

[17]More broadly, according to agency officials, a FHWA Division Office's oversight and stewardship role applies to many phases of program and project delivery. According to officials, FHWA Division Offices assist states in a range of ways, for example with project planning, design, construction, and maintenance as well as specifications, and procedures. FHWA Division Offices also perform project design reviews, construction inspections, and process reviews of selected program topics. Division Offices also participate in state research projects.

[18]Federal agencies or tribal governments are responsible for ensuring bridges they own are inspected.

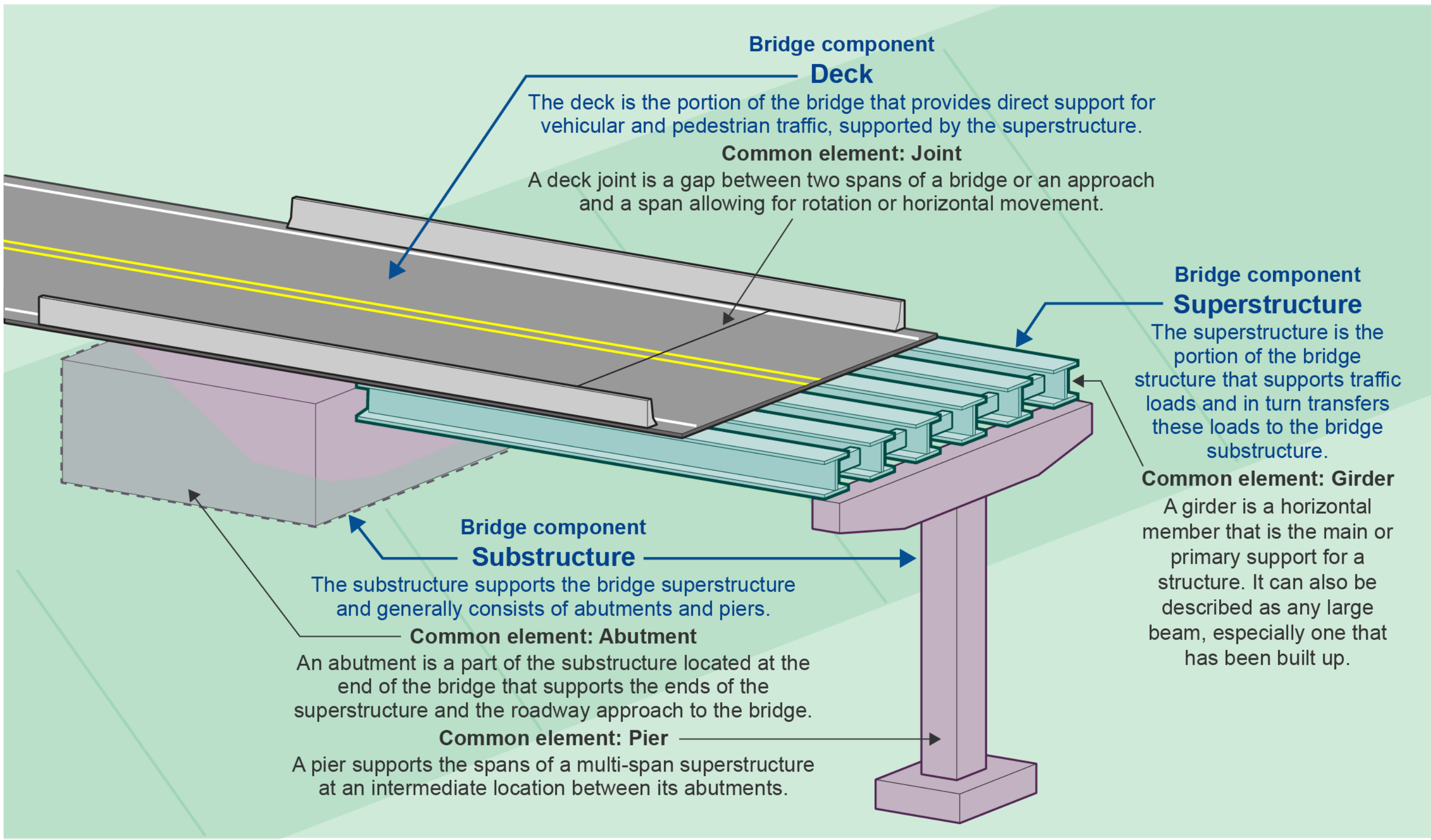
[19]Throughout our report we use FHWA definitions for the components and elements of a bridge as contained in the *Bridge Inspector's Reference Manual.* Department of Transportation, Federal Highway Administration, *Bridge Inspector's Reference Manual*. FHWA-NHI-16-013 (Arlington, VA: November 2015).

FHWA defines the superstructure as the portion of the bridge structure that supports traffic loads and in turn transfers these loads to the bridge substructure. The substructure supports the bridge superstructure and generally consists of abutments and piers. Finally, the deck is the portion of the bridge that provides direct support for vehicular and pedestrian traffic, supported by the superstructure.

[20]We are focusing our discussion in this report on the deck, substructure and superstructure. However, we included culverts (structures with fill over them) to measure total deck area.

piers and abutments (parts of the substructure).[21] Additionally, joints (part of a deck) can contribute to corrosion.[22] (See fig. 1.)

Figure 1: Major Components and Examples of Elements of a Bridge



Sources: GAO and Federal Highway Administration (FHWA). | GAO-21-104249

Note: This figure uses FHWA definitions for bridge components and elements.

[21]A girder is a horizontal member that is the main or primary support for a structure. It can also be described as any large beam, especially one that has been built up. A multi-girder bridge is one whose superstructure consists of three or more girders. A pier supports the spans of a multi-span superstructure at an intermediate location between its abutments. An abutment is located at the end of the bridge and supports the ends of the superstructure and the roadway approach to the bridge.

[22]A deck joint is a gap between two spans of a bridge or an approach and a span allowing for rotation or horizontal movement.

When state DOTs inspect NHS bridges, generally every 2 years, they must rate the bridge components on a 0 to 9 or N scale to characterize physical deficiencies of the bridge and submit these ratings into the National Bridge Inventory. FHWA, as part of its oversight role, uses the National Bridge Inventory data to classify the bridge as good, fair, or poor based on its lowest-rated component.[23] For example, if the lowest-rated component is the superstructure and it has a poor condition rating, then the bridge is classified as being in poor condition. In 2015, states began to report the condition of bridge elements for bridges on the NHS to the National Bridge Inventory as required by statute.[24] States report on 100 elements, and quantities of these elements are rated as condition states 1, 2, 3 and 4, which are defined as good, fair, poor and severe, respectively.[25]

Steel may be used in one or more of the FHWA-defined components and elements of a bridge and is subject to corrosion. Moreover, many concrete bridges also include steel in their components and elements. Of the approximately 146,000 NHS bridges in the U.S. in 2020, just over 45,000 are built of steel and just over 100,000 are built of concrete.[26] Corrosion forms when water or chemicals—such as from ocean spray or road deicers—come into contact with iron, a major component in steel, creating rust. Rust can lead to metal deterioration and loss of strength. Corrosion also occurs when water permeates concrete and reaches underlying steel. This steel expands as it rusts, causing the concrete to

[23]A good rating (7-9) indicates that the component is limited to only minor problems; a fair rating (5-6) indicates that the structural capacity of the component is not affected by minor deterioration, section loss, spalling, cracking, or other deficiency; and a poor rating (0-4) indicates that structural capacity is affected or jeopardized by advanced deterioration, section loss, spalling, or another deficiency. States may also rate a bridge component as N, which means “not applicable.”

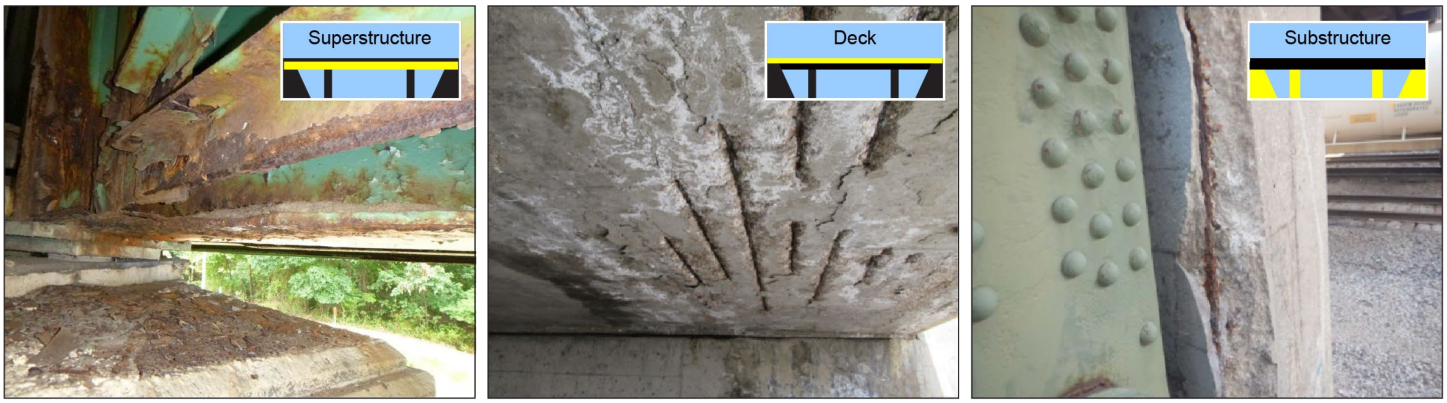
[24]23 U.S.C. § 144(d).

[25]An element condition state of 1 (good) means that there is no deterioration to minor deterioration present. A condition state of 2 (fair) means that deterioration is minor to moderate. A condition state of 3 (poor) means that deterioration is moderate to severe. A condition state of 4 (severe) means the deterioration is beyond the limits of condition state 3 or warrants a review to determine the strength or serviceability of the element or bridge.

[26]Although many bridges likely are comprised of both concrete and steel, a bridge is defined as a “concrete” bridge if its main span or spans are built of concrete. Similarly, a bridge is defined as a “steel” bridge if its main span or spans are built of steel. Main spans are those of greatest length within a bridge and are normally at the center of the feature being crossed.

crack or break off. (See fig. 2 for examples of corrosion in bridges' superstructure, deck and substructure.)

Figure 2: Photos Illustrating Corrosion on Bridges in Selected States



Corrosion on a steel girder.[a]

Area of deteriorating concrete with exposed corroded reinforcing bar.[b]

Area of deteriorated concrete and exposed, corroded reinforcing bar.[b]

Sources: Rhode Island Department of Transportation (left), Wyoming Department of Transportation (middle), and Kansas Department of Transportation (right). | GAO-21-104249

Note: This figure uses Federal Highway Administration (FHWA) definitions for bridge components and elements.

[a]A girder is any horizontal beam that is the main or primary support for a structure.

[b]Reinforcing bar, or rebar, is a steel bar, plain or with a deformed surface, which bonds to the concrete and supplies tensile strength to the concrete.

Performance-Based Approach

MAP-21 adopted a performance-based approach for the federal government's surface transportation programs, including programs providing funding for highway and bridge projects.[27] Specifically, MAP-21 required DOT to establish performance goals and measures to assess the condition of highways and bridges on the NHS in order to maintain them in a state of good repair. For the NHPP, FHWA established two

[27]MAP-21 § 1203 (codified as amended at 23 U.S.C. § 150). Prior to MAP-21, bridges were primarily funded through the Highway Bridge Program. This program was discontinued under MAP-21, but the act continued to fund bridges by establishing the National Highway Performance Program (NHPP) and expanding project eligibility for the Surface Transportation Block Grant Program. MAP-21 §§ 1106 (NHPP) (codified as amended at 23 U.S.C. § 119), 1108 (Surface Transportation Block Grant Program) (codified as amended at 23 U.S.C. § 133). The FAST Act did not substantially amend funding for NHS bridges.

performance measures for assessing the condition of NHS bridges.[28] One is the percentage of NHS bridges classified as in good condition, and the other is the percentage of NHS bridges classified as in poor condition.

To satisfy NHPP requirements, states must establish 2- and 4-year performance targets for these performance measures and report to FHWA every 2 years on the actual condition of their bridges and their progress towards achieving their targets.[29] States calculate their progress in achieving their performance targets using a formula that is set by regulation and based on deck area (the surface area that carries vehicles).[30] States are also required to develop a risk-based asset management plan to improve and preserve bridges, among other assets, on the NHS.[31] State efforts to transition to a performance-based, asset management approach are ongoing, with the first performance period ending on December 31, 2021.

[28]The regulations governing the NHPP performance measures for assessing bridge condition are located in 23 C.F.R. Part 490, Subpart D.

[29]The 2- and 4-year performance targets for these performance measures must reflect the anticipated condition of their NHS bridges at the corresponding midpoint and end of a 4-year performance period.

[30]This formula is located in 23 C.F.R. § 490.409(c).

[31]"Asset management" is a strategic and systematic process of operating, maintaining, and improving physical assets that focuses on engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions to achieve and sustain a desired state of good repair over the asset's lifecycle at minimum practicable cost. 23 U.S.C. § 101(a)(2); 23 C.F.R. § 515.5. In developing their asset management plans, states are required to include an inventory and description of the condition of pavement and bridge assets on the NHS in their state, asset management objectives and measures, performance gap identification, lifecycle cost and risk management analysis, a financial plan, and investment strategies. 23 U.S.C. § 119(e).

Bridges in Good Condition Have Declined since 2016, and Available Information Provides Some Insight into How Corrosion Affects Bridge Condition

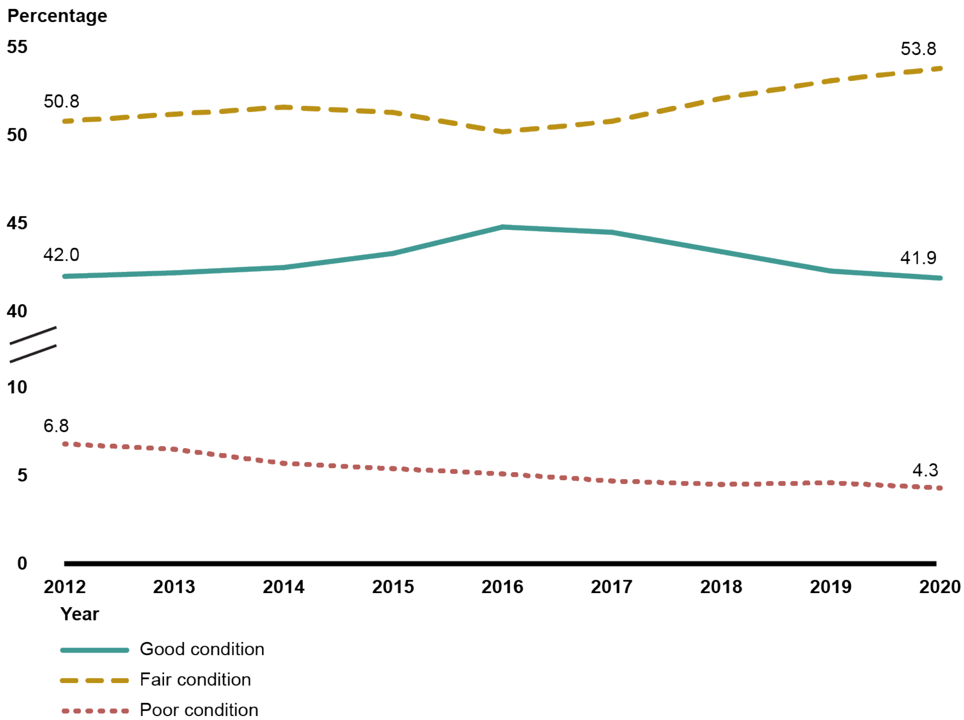
While Bridges in Poor Condition Have Decreased Steadily since 2012, Bridges in Good Condition Have Also Decreased in More Recent Years

Since 2012, the percentage of deck area for NHS bridges in poor condition has decreased, from 6.8 percent to 4.3 percent in 2020 (See fig. 3).[32] However, since 2016, the percentage of deck area for NHS bridges in good condition has also decreased each year overall (from 44.8 percent in 2016 to 41.9 percent), while the percentage of deck area for NHS bridges in fair condition has increased (from 50.2 percent to 53.8 percent). During this time period, the average age of bridges decreased from about 47 years in 2012 to just over 44 years in 2020. This decrease, according to FHWA officials, is the result of states replacing bridges that have deficiencies with new bridges. However, according to the American Society of Civil Engineers, the rate of deterioration on bridges is exceeding the rate of repair, rehabilitation, and replacement, and at the same time, the rate of bridges in fair condition is growing.[33]

[32]Bridges may vary significantly in size, and generally, the needs of larger bridges are more costly than those of smaller bridges. Measuring the total deck area, which accounts for the size of a bridge, provides more information than counting the number of bridges. The other bridge components, the substructure and superstructure, do not provide such information and thus we are not reporting on them here.

[33]American Society of Civil Engineers, *2021 Report Card for America's Infrastructure.*

Figure 3: Changes in the Condition of Deck Area for Bridges in Good, Fair, and Poor Condition on the National Highway System, 2012 through 2020



Source: GAO analysis of Federal Highway Administration data. | GAO-21-104249

As mentioned previously, bridge condition classifications are determined by the lowest condition rating of the major bridge components, namely the deck, substructure, and superstructure. According to the National Bridge Inventory data we analyzed, in 2020, of the 4,600 bridges in poor condition, just under 2,200, or 47 percent, had decks in poor condition, just over 2,000, or 44 percent, had superstructures in poor condition, and just over 1,400, or 31 percent had substructures in poor condition.[34] However, these data do not indicate the causes of the poor condition of these components, such as corrosion or some other factor, such as damage from vehicle collisions.

[34]Bridges can have more than one component in poor condition, thus the total number of bridges in poor condition will not equal the total number of decks, superstructures, and substructures in poor condition.

Available Information Provides Some Understanding of the Relationship between Corrosion and Bridge Condition

Studies we reviewed and stakeholders agreed that there is a significant relationship between corrosion and overall bridge condition. For example, according to one study we reviewed, corrosion is one of the most often-cited problems with steel bridges because it affects both the appearance and structural integrity of a bridge.[35] One study we reviewed cited another study that stated that the most common problems affecting bridge structures include "corrosion of the reinforced steel in concrete decks due to the penetration of chloride ions from deicing products, leakage through damaged joints, malfunction of frozen bearings, pronounced bumps at bridge approach slabs, and damaged coating systems."[36] A third study also stated that deck contamination by chloride compounds has two negative effects in a concrete deck. Specifically, a corroded steel bar suffers from loss of material, which reduces its structural capacity. Additionally, the rust that forms around corroded rebar increases exponentially and, as a result, compromises the serviceability and durability of the structure.[37]

In addition, officials from FHWA, DOTs in all five of our selected states, and all six of the associations we interviewed stated, in their view, there is a significant relationship between corrosion and bridge condition. For example:

- FHWA research officials said that it is well-understood that corrosion plays a significant role in bridge condition. Similarly, FHWA Division Office officials in offices representing our five selected states all agreed that corrosion plays a significant role in bridge condition.
- State DOT officials in one state noted that corrosion can be found in all major parts of a bridge in poor condition. An official in another state said corrosion is the primary driver of bridges in poor condition in that state because the design of many of its bridges is prone to corrosion.

[35]J. Peter Ault and Justin D. Dolph, National Cooperative Highway Research Program, NCHRP Synthesis 517 *Corrosion Prevention for Extending the Service Life of Steel Bridge: A Synthesis of Highway Practices* (2018).

[36]Mark D. Bowman and Luis M. Moran, Indiana Department of Transportation and Purdue University, *Joint Transportation Research Program, Bridge Preservation Treatments and Best Practices*, SPR-3617; FHWA/IN/JTRP-2015/22 (2015).

[37]Vellore S. Gopalaratnam, John Meyer, Kenny De Young, Abdeldjelil Belarbi and Huanzi Wang, (Missouri Transportation Institute and Missouri Department of Transportation, *Organization Research Report: Steel Free Hybrid Reinforcement System for Concrete Bridge Decks – Phase 1* ORO6.014 (May 2006).

Specifically, that state has more than 50 bridges with multiple girders, which experience the most corrosion.[38]

- Officials with all six of the associations we spoke with echoed the relationship between corrosion and bridge condition. For example, officials with the Association for Materials Protection and Performance noted that state DOT's recognize the need for bridge preservation because corrosion will cause reinforced concrete to deteriorate. Furthermore, officials with the American Society of Civil Engineers said that corrosion is a significant issue for the condition of bridges, particularly in states with roads on a coast or shoreline. These officials noted that those states constantly face salt from the ocean that causes corrosion and that states with high snowfalls also face corrosion from salt in road deicers.

Data from the National Bridge Inventory on the elements of a bridge in good, fair, poor, and severe condition can provide more specific information on bridge condition and state data can provide more specific information on how corrosion affects bridge condition. According to FHWA, element-level data help states to develop models used to predict bridge deterioration. Analysis of 2019 element-level data for all of the NHS bridges in poor condition in each of our selected states identified various elements with quantities reported in poor or severe condition, some of which are comprised of steel and could indicate the presence of corrosion.[39] For example, in one selected state, this analysis identified steel piles, abutments, movable bearings, and fixed bearings as having quantities of more than 30 percent in poor or severe condition.[40] According to FHWA and state DOT officials, while corrosion often causes steel elements to be in poor condition, the data do not include information on the specific underlying causes, such as corrosion. However, according to some of the state DOT officials we interviewed, states have been inspecting bridge elements for years prior to having to report element-

[38]Because girders are made of steel, multiple girders on a bridge present more places where corrosion can develop.

[39]As mentioned previously, we analyzed element-level data in order to identify examples of elements that had quantities in poor or severe condition.

[40]Piles are slender columns that support the substructure. They may be partially above ground or completely buried. Bridge bearings are places where the superstructure connects to the substructure. Moveable bearings are designed to allow for sideways movement in the superstructure while fixed bearings are designed to only allow for rotation.

level data to FHWA, and have documented corrosion in inspection reports when it has been identified.

States may also collect other data, known as defect data, which may indicate how corrosion affects NHS bridges.[41] Defect data categorizes deficiencies identified and documented during inspections using codes, including one that identifies corrosion on steel bridges. Three of our five selected states collect defect data.[42] Analysis of these data indicated some degree of corrosion on NHS bridges made of steel that are in poor condition.[43] For example, one selected state reported 30 steel bridges in poor condition, with corrosion present in elements on the superstructure of 27 bridges and on substructures of three bridges.[44] These data also provide information on how much corrosion is present. For example, for the 27 bridges with corrosion on the superstructure for this selected state, the state found corrosion on at least 50 percent of element quantities in fair condition for 26 of the bridges, and on at least 50 percent of element quantities in poor condition for one of the bridges. However, this defect code only applies to corrosion on steel bridges. There is no specific defect code that identifies corrosion on concrete elements, but a number of codes, such as efflorescence/rust staining, delamination, and spalling, can indicate the presence of corrosion.

[41]States are not required to collect defect data and thus do not submit them to the National Bridge Inventory. However, states that do collect defect data do so in accordance with the American Association of State Highway and Transportation Officials' (AASHTO) *Bridge Element Inspection Manual*.

[42]For the two selected states that do not collect defect data, one collects other data that allows it to determine the number of bridges that contain corrosion, and the extent to which corrosion affects bridges' condition. The other state does not collect any data on corrosion. However, examples of inspection reports from this state indicate that it does document in inspection reports corrosion identified during bridge inspections.

[43]As mentioned previously, for the states that collect defect data, two states provided data as of June 30, 2020. The other state provided data as of October 27, 2020 because its system could not go back to June 2020.

[44]Corrosion can be present on elements on more than one component of a bridge. For example, it can be present on a bridge's superstructure and substructure.

States Address Corrosion through a Variety of Practices but Face Challenges Transitioning to an Asset Management Approach

States Address Corrosion through a Variety of Prevention and Management Practices

According to studies we reviewed, federal and selected state officials, and officials from industry associations, the practices states use to prevent and manage corrosion throughout a bridge's lifecycle vary across the country and depend in part on the environment in which a bridge operates, the bridge's age and condition, and whether it is a concrete or steel bridge. Below we describe some of the practices used by states to address corrosion based on our review of the literature, along with examples of these practices used by our selected states to prevent and manage corrosion at various points in a bridge's lifecycle.

- **Design and Construction.** Bridges may be designed and constructed to reduce corrosion by using corrosion-resistant materials, such as weathering steel[45] or corrosion-inhibiting paints and coatings, or by reducing aspects of a bridge that are susceptible to corrosion. For example, states in arid climates, such as Wyoming, are likely to use weathering steel during construction, which slows corrosion and eliminates the need for painting. On the other hand, states that experience significant snow and ice in winter, such as Rhode Island and Illinois, may metalize or apply other protective coatings to bridges during bridge construction and maintenance to

[45]Weathering steel is designed to form a protective layer of rust. In certain situations, weathering steel may be inappropriate and result in excessive corrosion damage, such as in areas near the Atlantic, Pacific, or Gulf coast where the air is heavy with salt, or in areas with frequent high rainfall, high humidity, or frequent fog.

protect bridges from corrosion or manage existing corrosion.[46] Officials from three of the five selected states told us they use galvanized or metalized steel to prevent bridge corrosion. Finally, officials from three of five states said that their state eliminates or reduces the number of expansion joints when they construct bridges, because expansion joints often leak, and such leaks can cause corrosion.

- **Bridge inspection.** Bridge inspections help identify potential corrosion in a bridge component or element. Bridge inspection and monitoring practices include testing, visual inspections, sensors to monitor bridges, and electricity to determine the extent of any deficiencies. As previously mentioned, states are required to conduct routine inspections of NHS bridges on a regular basis, generally every 2 years. According to industry organizations and studies, corrosion can be difficult to detect during visual inspections because it can occur in steel components that are difficult to see. FHWA officials said that corrosion is generally detectable during routine inspections using visual and sounding techniques.[47] The officials also explained that there are situations when supplemental techniques are used to assist in detecting the extent of corrosion. For example, officials from one selected state said they use techniques, including ultrasonic or infrared testing to allow them to measure corrosion damage in areas of the bridge that are difficult to see.[48]

- **Maintenance.** Maintenance practices to reduce corrosion range from routine maintenance to maintain the condition of the bridge, such as debris removal, to bridge preservation and preventive maintenance activities to extend the service life of a bridge, such as bridge washing and the use of deck sealers. For example, officials from two selected states told us that they regularly wash or sweep some of their bridges

[46]Metalizing refers to the thermal spraying of zinc or aluminum alloys as a coating directly onto steel surfaces. Galvanizing, another method for applying metal to the surface of steel to control corrosion, can occur when steel is immersed into a vat of molten zinc, where it reacts with the iron in the steel to form a coating. Metalized coatings provide corrosion protection because these coatings tend to “sacrifice” themselves to protect the steel at the site of any damage in the coating. The coating also provides a barrier between the surface and the environment.

[47]Sounding techniques include tapping on the deck with a hammer or dragging a chain across the deck to detect delamination when concrete fractures into layers. Delamination also occurs in reinforced concrete when metal reinforcements (i.e., rebar) near the surface corrode.

[48]Ultrasonic testing can be used to find deficiencies in steel and concrete while infrared testing can be used to find deficiencies in concrete.

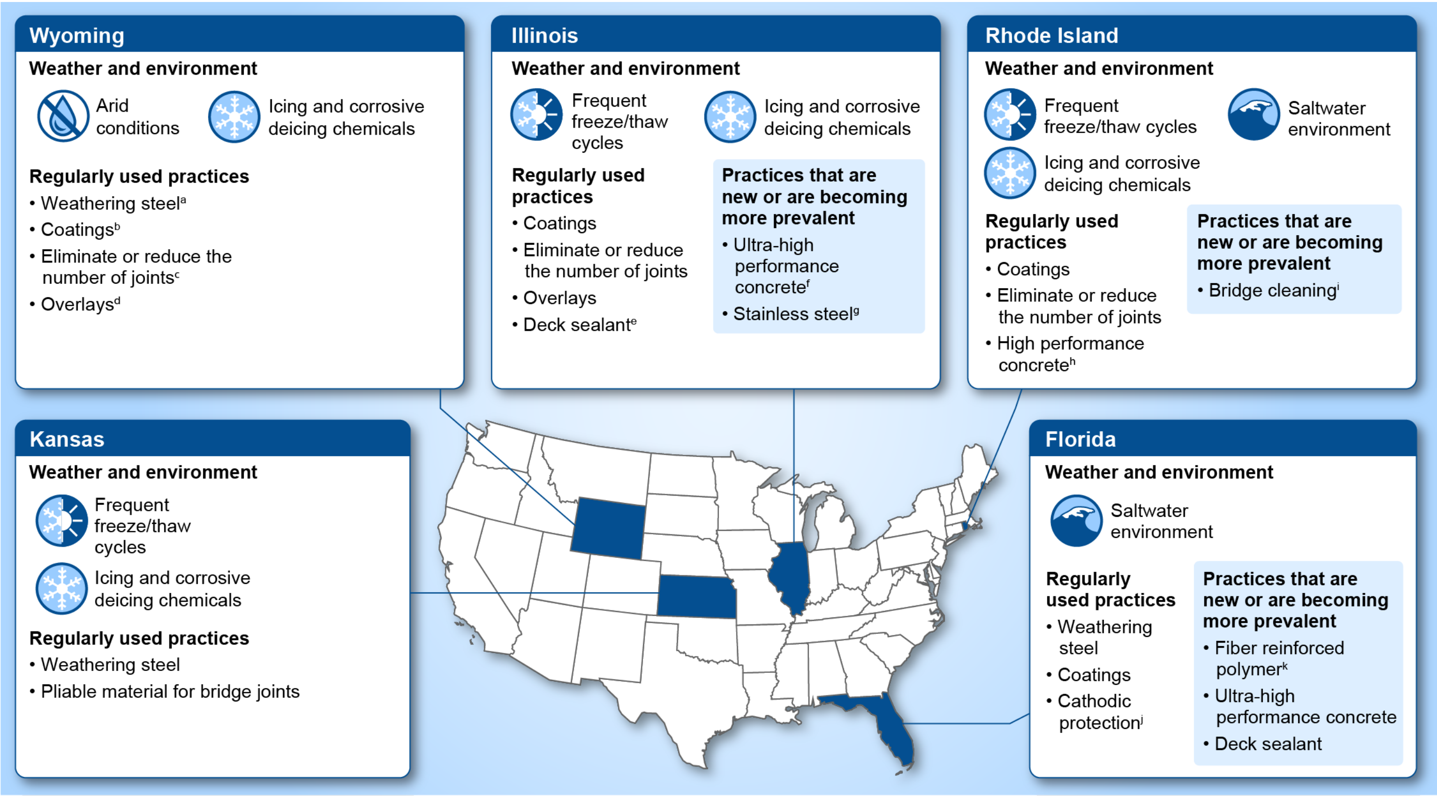
to remove debris and other materials that may accelerate the deterioration of bridge coatings, which can result in corrosion. In addition, officials from two selected states said that they maintain or clean the bridge joints as leaky bridge joints can cause corrosion.

- **Bridge rehabilitation and replacement.** Rehabilitation for deteriorated bridges involves major work—such as deck, superstructure, or substructure replacement—to restore a bridge's structural integrity or correct major safety defects, such as corroded steel elements. Officials from one state told us that to address bridge corrosion, they may rehabilitate corroded steel on bridges by adding a steel plate over a deteriorated section. Officials from two states told us they use techniques to rehabilitate or replace bridges, such as replacing corroded steel, or concrete in poor condition with components that include fiber-reinforced polymers or ultra-high performance concrete.[49] States may also replace deteriorated bridges in very poor condition.

Figure 4 illustrates common practices used to address corrosion among our selected states along with the climate conditions in those states. Additional information about corrosion practices used in the selected states can be found in appendix I.

[49]Fiber-reinforced polymer materials are composite materials that typically consist of strong fibers embedded in a resin matrix that are nonconductive, noncorrosive, and lightweight. The most common fibers are glass, carbon, and synthetic fibers.

Figure 4: Climate Conditions of Selected States and Common Practices That States Reported Using to Address Bridge Corrosion



Sources: GAO analysis and Map Resources. | GAO-21-104249

[a]Weathering steel is designed to form a protective layer of rust.

[b]Coatings are applied through activities such as painting, spraying, or dipping bridge components to prevent deterioration of structure components.

[c]A bridge joint is the space between bridge segments that allows for horizontal and vertical movement.

[d]An overlay is the topmost layer of material applied upon a roadway to receive the traffic loads and to resist the resulting disintegrating action.

[e]Deck sealants and crack sealers prevent contaminants from deicing materials spread on the road from penetrating into the concrete bridge deck and corroding the steel reinforcing bars.

[f]Ultra-high performance concrete is a class of concrete that has been developed in recent decades for its strength and durability.

[g]Stainless steel is a form of steel that is resistant to rust.

[h]High-performance concrete is concrete that has been designed to be more durable and, if necessary, stronger than conventional concrete.

[i]Bridge cleaning refers to removing contaminants by washing or sweeping bridges.

[j]Cathodic protection systems help prevent corrosion from occurring on steel by substituting a new source of electrons called an “anode.” The anode is more electrochemically active than the metal to be protected within a given environment and the corrosion occurs on the anode instead of the steel.

[k]Fiber-reinforced polymer materials are composite materials that typically consist of strong fibers embedded in a resin matrix that are nonconductive, noncorrosive, and lightweight. The most common fibers are glass, carbon, and synthetic fibers.

[l]Officials from Wyoming and Kansas did not provide information about practices that are new or are becoming more prevalent and that they are using to address corrosion.

Most Selected States Prioritized Replacing Bridges, but Officials Said More Information on Approaches' Effectiveness to Address Corrosion Could Help Shift the Focus to Preservation

As previously discussed, MAP-21 required states to develop a risk-based asset management plan to improve or preserve the condition of their transportation infrastructure and the performance of the NHS to satisfy NHPP requirements.[50] These plans include the states' 2- and 4-year targets for bridge condition.[51] Officials from the five selected states have established asset management plans that focus on bridge preservation. According to FHWA's Bridge Preservation Guide and regulations, under an asset management approach states are to:

- adopt and implement bridge preservation activities, such as strategies that prevent, delay, or reduce deterioration of bridges or bridge elements to maintain bridges in good and fair condition for as long as possible[52] and
- develop a structured process focused on actions to achieve and sustain a state of good repair over the entire lifecycle of a bridge at a minimum practical cost, as required by regulation.[53]

Specifically, the approach entails adopting strategies to prevent and manage corrosion over the full lifecycle of a state's bridge inventory. FHWA noted in its report on long-term asset management that by its very nature, asset management assumes a long-term view requiring a long-term strategic approach.[54] Additional FHWA guidance notes that the benefits of strategies that minimize lifecycle costs can be realized by adopting a long-term view compared to strategies that focus on short-

[50]MAP-21 § 1106 (codified as amended at 23 U.S.C. § 119).

[51]23 C.F.R. § 515.9. FHWA published information in May 2021 on states' progress in meeting their targets through 2020. We did not evaluate states' progress for purposes of this report.

[52]FHWA, *Bridge Preservation Guide: Maintaining a Resilient Infrastructure to Preserve Mobility,* FHWA-HIF-18-022 (Washington, D.C.: Spring 2018).

[53]23 C.F.R. § 515.7.

[54]FHWA, *Beyond the Short Term: Transportation Asset Management for Long-Term Sustainability, Accountability and Performance*. Pub. No. FHWA-IF-10-009.

term gains.[55] Accordingly, FHWA requires state DOTs to include a financial plan covering at least a 10-year horizon in their asset management plans.[56]

Officials from four of the five selected states said that their state had historically taken a "worst-first" approach to addressing deterioration and corrosion—meaning the state dedicated resources to repair, rehabilitate, or replace bridges that were in the worst condition and had not prioritized maintenance and preservation of bridges that were in better condition. As a result, according to officials from these states, the transition to an asset management approach that takes into account the full lifecycle of a bridge will take time to implement. For example, officials from these states said that they are in different stages of transitioning to an asset management approach.[57] In addition, they said the benefits from the shift would likely not be realized in the near-term. For example, officials from two of the four selected states told us that their states had developed or are developing a bridge preventive maintenance program. Officials from one of these states said that they are currently working with FHWA Division Office officials on a formal bridge preservation program, which includes having contractors on call to address corrosion and other bridge preservation issues. The state officials said they hoped to implement the bridge preservation program in 2020 but were delayed due to the loss of state revenue as a result of the COVID-19 pandemic.

In contrast, officials from one selected state said they do not take the "worst-first" approach and address corrosion by prioritizing funding to ensure its bridges are adequately preserved and maintained. The officials told us they deal with corrosion throughout the lifecycle of the bridge, for example, by designing bridges to prevent corrosion and addressing corrosion when it is found instead of waiting until the bridge is approaching poor condition. In addition, when the state identifies corrosion on a bridge in good condition, it addresses it with bridge preservation activities, such as painting, repainting, and spot painting bridges to keep them in good condition.

[55]FHWA, *Developing TAMP Financial Plans, Final Document* (November, 2017).

[56]23 C.F.R. §§ 515.5, 515.9.

[57]Two selected states have started to transition to an asset management approach in the last 5 years, while the other two have plans to transition when funding allows.

In addition, selected state and association officials identified challenges that could affect their ability to fully implement an asset management approach that would help address bridge corrosion. These challenges include funding and resource limitations and a lack of information about what practices to use to address corrosion in differing circumstances.[58]

- **Funding and resources.** Officials from the five selected states and association officials said that implementing bridge preservation practices requires up-front investment, which may constrain limited budgets in the short-term. For example, according to its transportation asset management plan, one selected state that used a "worst-first" approach determined that to shift to an asset management approach to help preserve the condition of existing bridges, it would need an immediate 33 percent increase in available funding to achieve its bridge targets in 10 years. In addition, officials from the five selected states and association officials said that states face competing demands and priorities for funding and resources. For example, an official from one selected state said the state DOT would like to routinely paint areas of bridges prone to corrosion, but faces competing demands for funding based on the condition of other infrastructure.

  Officials from one association said funding for bridge maintenance usually comes from the state, and states may prioritize congestion relief and building new highways and bridges over maintenance of existing bridges. As a result, some corrosion will likely go untreated, requiring more expensive repairs in the future. FHWA has stated that due to limited funds and increased competition for funds among highway assets, bridge owners are challenged to cost effectively preserve and maintain their bridges to support overall highway mobility.[59] Officials from another selected state said they are short of staff because of funding cuts and, consequently, do not have enough staff to perform routine maintenance tasks, such as washing bridges.

[58]We have previously reported that expanding project and activity eligibility for federal funding has provided states with more flexibility for bridge preservation activities on their bridges, but according to FHWA, jurisdictions traditionally have had some incentive to allow bridges to fall into poor condition because funding has historically been provided to states, with a focus on percentages that are poor. We also found that DOT did not measure the link between funding and performance, such as maintained or improved bridge conditions and recommended that DOT develop an efficiency metric. See GAO-16-779. In 2020, DOT developed an efficiency metric that incorporates bridge funding and improvement in bridge conditions.

[59]FHWA, *Bridge Preservation Guide* (2018).

Officials from an association reiterated these concerns, telling us that budgets are the most challenging issue facing states in addressing corrosion.

- **Information on effective practices to address corrosion.** Officials from the five selected states also said that more information on the circumstances in which to use certain bridge preservation practices to address corrosion—essential under an asset management approach—could help states make more informed decisions, especially in light of limited funds and resources to conduct their own research. For example, while officials from two of the selected states said they have conducted some in-house research on whether bridge preservation practices, such as ultra-high performance concrete, are effective, officials from the other three selected states said they do not have the ability to conduct this type of research and instead rely on external sources for such information.[60] Officials from one of these states told us they were not sure how effective bridge washing was relative to other practices for addressing corrosion, such as painting. Officials from another state said they use painting as a significant part of their corrosion management strategy but are uncertain how often they should repaint their bridges. In addition, officials from three of five selected states told us they use sealant on bridge decks to protect against corrosion, but officials from another selected state said they do not use sealant because they do not know if it is an effective use of their funds, relative to other practices.

Officials from selected states and an association said that states need more help in obtaining information about practices to prevent and manage corrosion. Officials from all the selected state DOTs said they regularly speak with DOT officials in other states about corrosion practices, but officials from all of the selected states thought that there could be more communication among states and from FHWA. For example, officials from one state DOT said while they have a good understanding of the corrosion practices they currently use, they do not have a good understanding of the effectiveness of practices other states use. Officials from two selected states said they are also

[60]According to studies from the University of Washington and the National Cooperative Highway Research Program, bridge washing has become more common. Jeffrey W. Berman, Charles W. Roeder, and Ryan Burgdorfer, Determining the Cost/Benefit of Routine Maintenance Cleaning of Steel Bridges to Prevent Structural Deterioration (Seattle, Washington, September, 2013) and National Academy of Sciences, *NCHRP Synthesis 517, Corrosion Prevention for Extending the Service Life of Steel Bridges, A Synthesis of Highway Practice* (Washington, D.C.: 2018).

beginning to use other practices to prevent and manage corrosion, such as ultra-high performance concrete, stainless steel, and fiber reinforced polymers. Thus, they could benefit from other states' experience with these practices. Some officials also suggested ways FHWA could assist states' approaches to preserving bridges, as we discuss later in this report.

FHWA Assists States through Research and Technical Assistance, but Current Efforts May Not Address Selected States' Need for Additional Information on Specific Corrosion Practices

FHWA Assists States through Research and Technical Assistance

While states are responsible for selecting and prioritizing which infrastructure projects in their state will receive federal funding, FHWA is generally responsible for ensuring that infrastructure on the NHS—including bridges—continues to be safe for public travel. FHWA does this by conducting oversight of states' bridge inspection programs to ensure they adhere to federal inspection standards and by providing financial and technical support to state governments to assist them in bridge design, construction, and maintenance. FHWA assists states in addressing bridge corrosion through research and technical assistance activities, in the following ways:

Research

FHWA conducts research at its Turner-Fairbank Highway Research Center in McLean, Virginia, funds research conducted by partners,[61] facilitates state research, and publishes studies and reports, some of which relate to corrosion, as described below.

[61]Partners include other government agencies, academia, and private industry.

- According to FHWA officials, the Coatings and Corrosion Laboratory focuses on corrosion, and other Turner-Fairbank laboratories, including the Nondestructive Evaluation Laboratory, conduct research that relates to identifying, preventing, and managing corrosion. Turner-Fairbank officials told us that this research is intended to develop and provide information for states to inform their decisions about their bridges and highways. For example, in 2018 Turner-Fairbank published the results of its study on how different types of grout affect the corrosion of tendons.[62]
- As part of the Long-Term Bridge Performance Program—a long-term research program authorized by statute in 2005 to collect high-quality data from a representative sample of highway bridges nationwide—FHWA is collecting data on a sample of bridges using techniques beyond those used in typical inspections to provide more detailed information on bridge condition.[63] As previously discussed, the component and element-level data FHWA collects from states do not identify the specific causes behind deterioration in bridge condition. FHWA officials stated that at present, this effort focuses on bridge decks because of feedback from state DOTs that deterioration of bridge decks, some of which can be caused by corrosion, is a significant challenge. FHWA plans to expand the program to other parts of bridges, including joints, which can cause corrosion when they fail, and bearings, which may be subject to corrosion. While this project will likely provide information to states regarding the challenges identified previously, it is a long-term effort and does not address all parts of bridges that are subject to corrosion.
- FHWA also administers the Transportation Pooled Fund Program, which allows state DOTs to combine resources with other states, commercial entities, and FHWA program offices for shared research goals. For example, as of June 2021, through a pooled fund study a group of state DOTs are developing a bridge-deck preservation tool that will allow states to identify cost-effective maintenance practices, including how to address corrosion.

[62]A tendon is a cable, strand, or bar used in prestressing, a construction technique where forces are applied to a structure in such a way that it will withstand loads better. William H. Hartt and Seung-Kyoung Lee, *Corrosion Forecasting and Failure Projection of Post-Tension Tendons in Deficient Cementitious Grout* (May 2018).

[63]The Long-Term Bridge Performance Program was authorized by the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users. Pub. L. No. 109-59, § 5202, 119 Stat. 1144, 1785 (2005). The intent of the program is to help the bridge community to better understand bridge performance.

- FHWA officials told us they partner with organizations, including AASHTO, to provide information to states on recent research developments, some of which relate to bridge corrosion. For example, representatives of state DOTs have input on how FHWA prioritizes research funding, including funding for corrosion research, through AASHTO regional bridge preservation partnerships.

Technical Assistance

FHWA officials told us FHWA responds to requests from states for technical assistance on specific projects or practices, some of which can relate to bridge corrosion. In addition, FHWA provides technical assistance in the form of training, guidance, and information sharing to states. For example:

- FHWA's National Highway Institute provides training to state DOT personnel on bridge inspection and other topics related to corrosion, and FHWA officials told us they have offered training to help states as they transition to an asset management approach.
- FHWA publishes guidance documents such as the *Steel Bridge Design Handbook*, which provides information on the use of different materials and coatings to prevent corrosion.[64]
- In 2010, FHWA created a group that focuses on sharing information on bridge preservation, known as the Bridge Preservation Expert Task Group. FHWA chairs this group to provide a forum to exchange information on bridge preservation, including corrosion. Members include FHWA, state DOTs, AASHTO, academia, industry, and county and local governments. FHWA officials told us the task group has issued products to help states make better-informed decisions in the form of pocket guides and smartphone applications. For example, *A User's Guide to Bridge Cleaning* describes considerations involved in planning and carrying out a bridge cleaning program, which it describes as a way to mitigate corrosion. The task group also produced a *Bridge Preservation Guide*, which outlines bridge preservation approaches, some of which relate to corrosion. The task group plans to issue additional pocket guides on the use of individual practices, some of which FHWA officials told us are planned to relate to corrosion. For example, FHWA officials told us the task group plans

[64]Department of Transportation, Federal Highway Administration, *Steel Bridge Design Handbook: Corrosion Protection of Steel Bridges,* FHWA-HIF-16-002 - Vol. 19 (Washington, DC: December 2015).

to issue a guide dealing with cathodic protection systems, which are a technology that can slow corrosion.[65]

FHWA Assistance May Not Address Selected States' Needs for Information on Effectiveness of Specific Corrosion Practices

According to FHWA's 2019 *Status of Nation's Highway, Bridges, and Transit Conditions and Performance* report, preservation actions are a key strategy to achieving a state of good repair. In particular, according to the report, applying a preservation treatment at the right time (when), on the right project (where), with quality materials and construction (how), offer a proven, cost-effective approach to extending the overall service life of bridges with fewer costly repairs. Additionally, *Federal Standards for Internal Control* call for agencies to externally communicate the necessary quality information to achieve their objectives. Therefore, it is important for FHWA to communicate to states the necessary information for them to make informed decisions about bridge preservation actions, including addressing corrosion, as they continue to transition to an asset management approach.

However, as previously discussed, selected states said they faced challenges related to a lack of information about what practices to use to address corrosion in differing circumstances. For example, states had different views on the effectiveness of practices including bridge cleaning and deck sealing. In addition, some state officials identified ways that FHWA could better help them address bridge corrosion. Officials from one state said FHWA could develop more detailed information on preservation approaches and techniques for preventing and managing corrosion, and officials from an association said that states could benefit from FHWA's sharing examples and best practices for preventing and managing corrosion. Officials from another state thought that FHWA could help develop more information regarding the best time to try to mitigate factors, such as chlorides in road salt that may result in corrosion in bridges.[66]

It is unclear the extent to which FHWA's ongoing efforts will provide states with the information they said they need to more effectively address corrosion, and some of these efforts, such as the Long-Term

[65]Cathodic protection systems help slow corrosion from occurring on steel by substituting a new source of electrons called an "anode." The anode is more electrochemically active than the metal to be protected within a given environment, and the corrosion occurs on the anode instead of the steel.

[66]This state participated in a discussion we had with an association and was not one of the five selected states.

Bridge Performance Program, will take time to produce useful results. For example:

- The FHWA guide to bridge cleaning provides information on how to plan and carry out bridge cleaning and recommends the practice, but does not provide information to help a state decide whether or not it is worthwhile to clean a specific bridge over another or whether or not to prioritize bridge cleaning over other corrosion practices. This information could include, for example, the kinds of bridges or bridge conditions that might make cleaning a priority. In addition, the guide acknowledges that the benefits of bridge cleaning compared to service life are still being researched and will vary based on factors, such as the environment the bridge is in and the quality of the bridge's original construction.
- Likewise, FHWA's *Bridge Preservation Guide* identifies practices that can be part of a bridge preservation approach but does not provide information about the types of situations or kinds of bridges where the practices are most effective.
- In 2019, FHWA issued a congressionally directed report summarizing bridge corrosion prevention and control best practices used by states.[67] However, the report did not provide information to help states determine the practices best suited for the specific bridges and conditions in their state.

If future FHWA products, such as the forthcoming guide to cathodic protection, follow this model, they may not address states' needs to understand when and on which bridges specific practices are likely to be most effective.

According to FHWA officials, FHWA's past focus has been on addressing bridge condition at a policy level, and they expected that states would use the more detailed data available on their bridges to determine which

[67]Staff of H. Comm. On Appropriations, 115th Cong., Explanatory Statement of Consolidated Appropriations Act, 2018, Book 2, at 1913 (Comm. Print 2018) (incorporating H.R. Rep. No. 115-237 at 35 (2017); Staff of H. Comm. On Appropriations, 115th Cong., Explanatory Statement on Consolidated Appropriations Act, 2019, at 896 (Comm. Print 2019) (incorporating H.R. Rep. No. 115-750, at 34 (2018)); and Department of Transportation, Federal Highway Administration, *Report on Best Practices for Corrosion Control and Mitigation* (Washington, D.C.: September 2019).

corrosion practices to use.[68] In addition, according to FHWA officials, they do not recommend which specific corrosion practices states should use as states are best positioned to make these decisions based on their unique circumstances. In its 2019 congressionally directed report, FHWA concluded that due to the complexity of the problem of bridge corrosion, there is no one-size-fits-all approach.[69] However, FHWA officials acknowledged that they do have a role in influencing states to make well-informed decisions. They also recognized that not all states have the resources to conduct research on the effectiveness of different corrosion practices.

FHWA officials said they can use activities, such as peer exchanges between states and case studies of state practices to share information about specific approaches to corrosion. FHWA officials stated that these activities can provide useful information to states on the potential benefits of an approach, even for practices, such as bridge cleaning as mentioned above, where research is still ongoing to determine the circumstances in which they are most effective. FHWA officials told us that these activities have been successful in the past in providing information to states, although these activities have not necessarily addressed corrosion. Conducting these activities more regularly and with a specific focus on the challenges states face with regard to corrosion practices may be a way for FWHA to better assist states. For example, officials at two FHWA Division Offices stated that they could better assist their states with corrosion by supporting more peer exchanges. Officials from selected states likewise stated that their states would benefit from FHWA's facilitating more information sharing between states on corrosion practices. The Bridge Preservation Expert Task Group has indicated it plans to conduct such activities in its strategic plan, but the extent to which its efforts will relate to corrosion is unclear.

As states continue transitioning to an asset management approach that emphasizes bridge preservation, providing them with additional information that includes the circumstances in which different corrosion practices are most effective would help states make decisions about prioritizing resources. In addition, as previously discussed, officials from two of our selected states told us they are exploring using new corrosion

68FHWA officials told us that FHWA does not endorse the use of specific practices for states to use to manage corrosion.

69Department of Transportation, Federal Highway Administration, *Report on Best Practices for Corrosion Control and Mitigation* (Washington, D.C.: September 2019).

practices and could therefore benefit from additional information on the situations in which such practices are most effective. Therefore, as FHWA continues its work on bridge preservation and to meet its objective of ensuring that the nation's roads and highways continue to be among the safest in the world, it will be important for FHWA to ensure that its future bridge preservation activities help states make well-informed decisions about the use of various practices to prevent and manage corrosion for different types of bridges in different environments.

Conclusions

Maintaining the condition of NHS bridges is an important part of the overall safety of the nation's highways, and FHWA provides billions in funding each year for highway and bridge projects that include bridge rehabilitation and maintenance. States and FHWA recognize that corrosion is a significant factor in the deterioration of NHS bridges, but states reported that they need more information on the circumstances in which to use various practices to address corrosion on specific types of bridges in specific environments. FHWA has long-term efforts under way to better understand bridge corrosion, but it is important for FHWA to provide information to states on situations in which to use specific practices in the interim. By ensuring that its activities provide information to states on the circumstances in which various practices can be most effective, FHWA can help states preserve their bridges as they transition from the traditional "worst-first" approach to an asset management approach focused on proactive bridge preservation. Moreover, this information could help address recent declines in the number of NHS bridges in good condition coupled with increases in the number of bridges in fair condition.

Recommendation for Executive Action

The Administrator of FHWA should ensure that FHWA's ongoing bridge preservation efforts include activities, such as peer exchanges and case studies that focus on addressing the challenges states face with determining the circumstances under which specific corrosion practices and materials are most effective. (Recommendation 1)

Agency Comments

We provided a copy of this draft to DOT for its review and comment. DOT concurred with our recommendation and provided technical comments, which we incorporated as appropriate. DOT's comments are reprinted in appendix II.

We are sending copies of this report to appropriate congressional committees and the Secretary of Transportation. In addition, this report is available at no charge on the GAO website at http://www.gao.gov

If you or your staff have any questions about this report, please contact me at (202) 512-2834 or vonaha@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix III.

Andrew Von Ah
Director, Physical Infrastructure

Appendix I: Selected States' Information on the National Highway System's Bridges and Corrosion Practices

Corrosion forms when water or chemicals—such as from ocean spray or road deicers—come into contact with iron, a major component in steel, creating rust. Rust can lead to metal deterioration and loss of strength. Corrosion also occurs when water permeates the concrete and reaches underlying steel. This steel expands as it rusts, causing the concrete to crack or break off. We found that the types of practices states use to prevent and manage National Highway System's (NHS) bridge corrosion vary and depend on the environment in which a bridge operates. The following presents information on bridge characteristics in each of the selected states along with factors that contribute to bridge corrosion and practices used to address corrosion in the state.[1]

Florida

Characteristics of National Highway System (NHS) Bridges

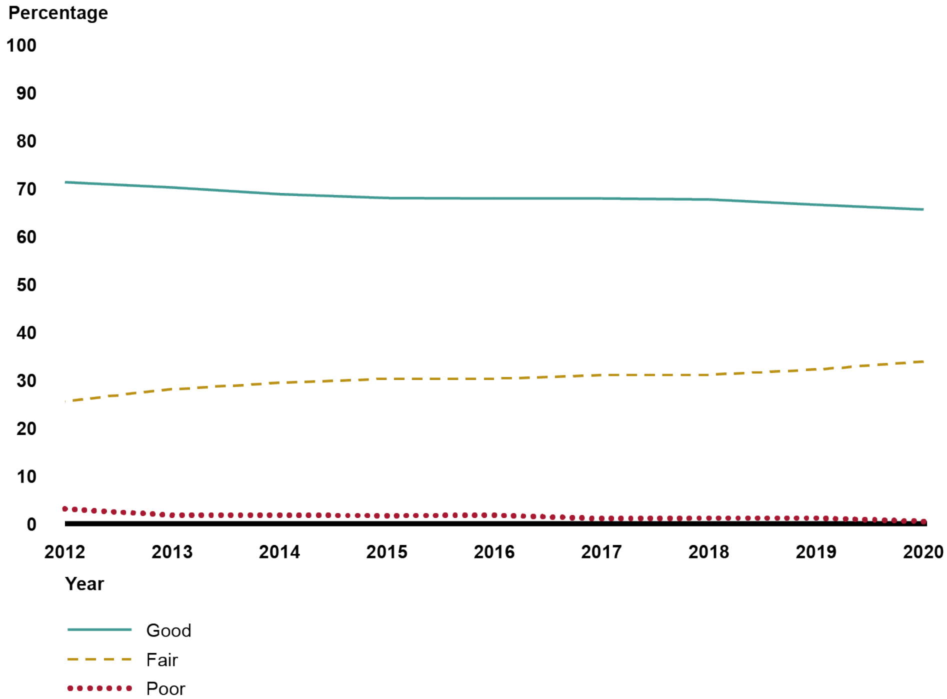
- Number of NHS bridges: 5,654[2]
- Number of Concrete Bridges: 4,953
- Number of Steel Bridges: 700
- Average age of NHS bridges: 37.5 years

[1]We present information on bridge condition based on deck area. Bridges may vary significantly in size, and generally, the needs of larger bridges are more costly than those of smaller bridges. Measuring the total deck area, which accounts for the size of a bridge, provides more information than counting the number of bridges

[2]Florida has one additional bridge that is not concrete or steel. For example, some states also have bridges made of timber.

Condition of NHS Bridges, 2012-2020

Figure 5: Percentage of the National Highway System's Bridge Deck Area Reported to be in Good, Fair, and Poor Condition in Florida, 2012-2020



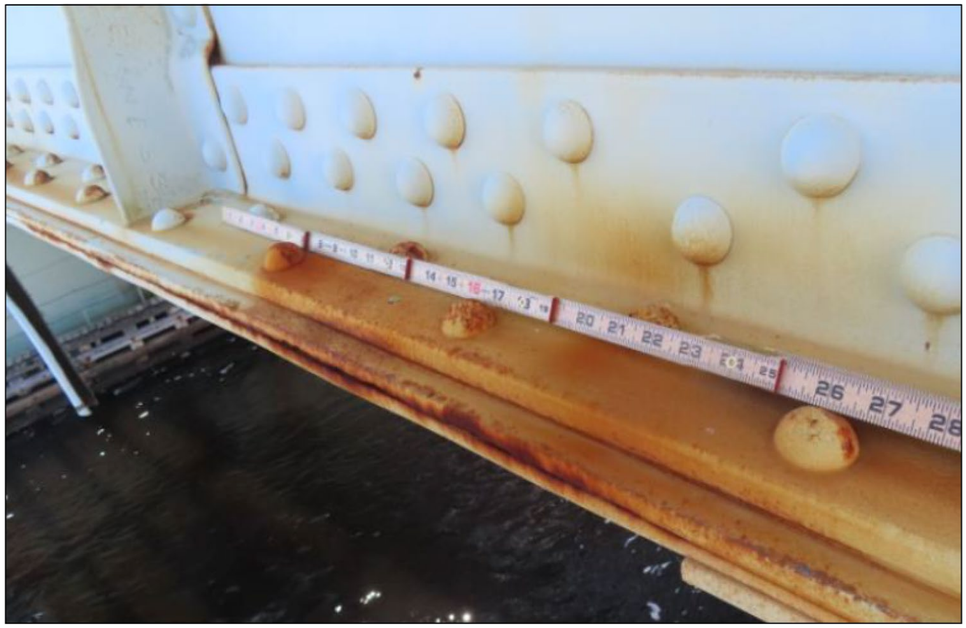
Source: GAO analysis of Federal Highway Administration information. | GAO-21-104249

Environmental Factors Affecting Bridge Corrosion

The Florida Department of Transportation (FDOT) officials said that they typically find corrosion in the substructure of bridges and that the worst instances of corrosion occur on bridge components directly exposed to saltwater from the Atlantic Ocean and the Gulf of Mexico. Florida has bridge structural guidelines that vary for different environments, such as using weathering steel in more mild environments.[3] See fig. 6 for a photo of corrosion on a bridge in Florida.

[3] A "mild" environment has little to no exposure to natural airborne and applied deicing salts and is usually an inland location.

Figure 6: Photo of Corrosion on a National Highway System Florida Bridge



This steel beam has corrosion with section loss.

Source: Florida Department of Transportation. | GAO-21-104249

Practices to Manage or Prevent Corrosion

FDOT officials said that saltwater is a major factor in corrosion in Florida. In constructing its bridges, Florida officials said the state regularly uses weathering steel, and uses stainless steel, fiber reinforced polymer[4] and ultra-high performance concrete on a limited basis. FDOT officials said that they address corrosion when it is found. For example, FDOT may mitigate corrosion by recoating the bridge. FDOT has also been using deck sealant more often as the bridges age. In addition, Florida has several bridges that are difficult to inspect, and its inspectors use non-destructive testing, such as ultrasonic and infrared testing, to measure

[4]Fiber-reinforced polymer materials are composite materials that typically consist of strong fibers embedded in a resin matrix that to increase the strength of the concrete and are nonconductive, noncorrosive, and lightweight. The most common fibers are glass, carbon, and synthetic fibers.

damage in areas of the bridge that are difficult to see. Florida also uses cathodic protection to protect its bridges from corrosion.[5]

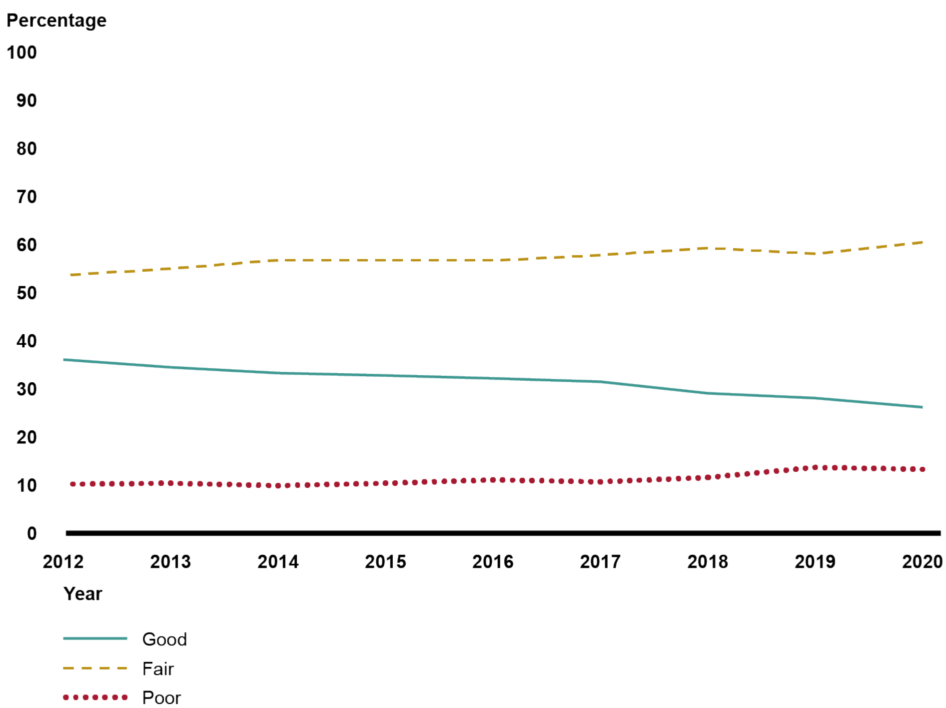
Illinois

Characteristics of NHS Bridges

- Number of NHS bridges: 4,819[6]
- Number of concrete bridges: 2,209
- Number of steel bridges: 2,607
- Average age of NHS bridges: 44.1 years

Condition of NHS Bridges, 2012-2020

Figure 7: Percentage of the National Highway System's Bridge Deck Area Reported to be in Good, Fair, and Poor Condition in Illinois, 2012-2020



Source: GAO analysis of Federal Highway Administration information. | GAO-21-104249

[5]Cathodic protection systems help slow corrosion from occurring on steel by substituting a new source of electrons called an "anode." The anode is more electrochemically active than the metal to be protected within a given environment, and the corrosion occurs on the anode instead of the steel.

[6]Illinois has three additional bridges that are not concrete or steel.

Environmental Factors Affecting Bridge Corrosion

According to officials from the Illinois Department of Transportation (IDOT), corrosion is a significant issue in the state and a common reason some bridges are in poor condition. Usually corrosion can be found in all major components of a poor condition bridge in the state, including deck, superstructure, and substructure. In addition, Illinois experiences frequent freeze-thaw cycles and uses deicers to clear the roads of snow and ice, an approach that can also cause bridge corrosion. See fig. 8 for an example of corrosion on a bridge in Illinois.

Figure 8: Photo of Corrosion on a National Highway System's Illinois Bridge

This steel beam shows corrosion due to paint failure with possible section loss.

Source: Illinois Department of Transportation. | GAO-21-104249

Practices to Manage or Prevent Corrosion

IDOT officials said that the state uses common practices to design, construct, and maintain bridges to manage and prevent corrosion. For example, in constructing its bridges, IDOT has eliminated or reduced the number of bridge joints to reduce opportunities for corrosion and uses stainless steel and ultra-high performance concrete on a limited basis. The officials said that IDOT uses overlays, deck sealants, and coatings, such as paint, particularly on steel girders, to mitigate corrosion during bridge maintenance. Finally, IDOT uses cathodic protection on some of its older bridges to slow the progress of corrosion.

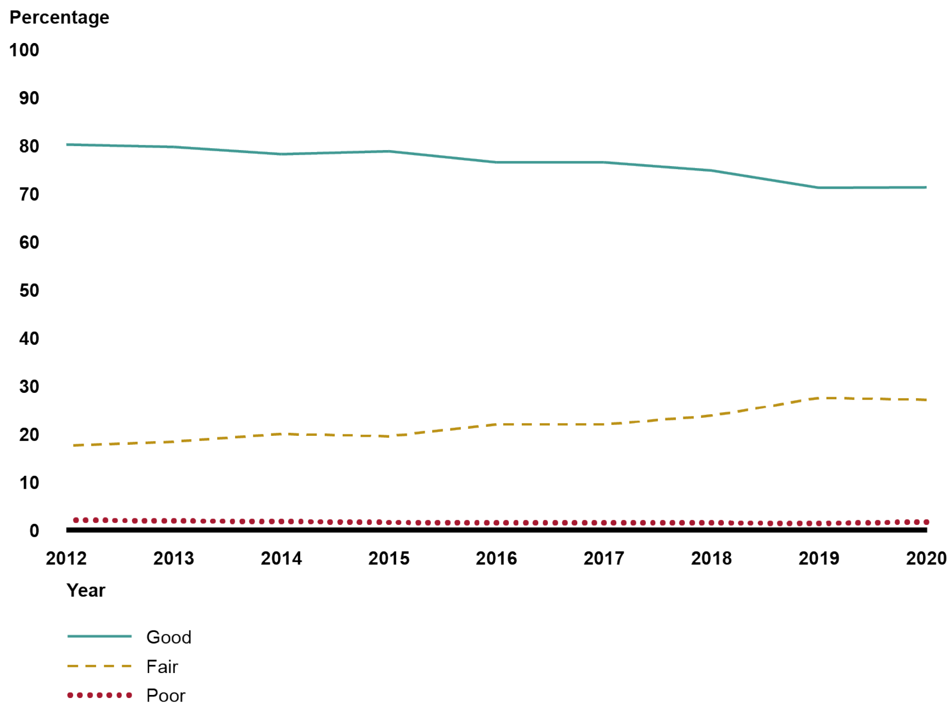
Kansas

Characteristics of NHS Bridges

- Number of NHS bridges: 2,844
- Number of concrete bridges: 2,109
- Number of steel bridges: 735
- Average age of NHS bridges: 43.2 years

Condition of NHS Bridges, 2012-2020

Figure 9: Percentage of the National Highway System's Bridge Deck Area Reported to be in Good, Fair, and Poor Condition in Kansas, 2012-2020



Source: GAO analysis of Federal Highway Administration information. | GAO-21-104249

Environmental Factors Affecting Bridge Corrosion

According to officials from the Kansas Department of Transportation (KDOT), the primary cause of corrosion on bridges in the state is deicing chemicals. Kansas experiences frequent freeze-thaw cycles and, as a result, uses deicing chemicals to clear its bridges of ice and snow. The

KDOT's officials said they could effectively control bridge corrosion in the state if they could keep the deck joints sealed and prevent water and deicing chemicals from leaking onto the bridge girders. See fig. 10 for an example of corrosion on a bridge in Kansas.

Figure 10: Photo of Corrosion on a National Highway System Kansas Bridge

This bridge has corrosion resulting from leaking bridge joints.

Source: Kansas Department of Transportation. | GAO-21-104249

Practices to Manage or Prevent Corrosion

KDOT officials said that corrosion in their state is usually found on the bridge deck, even decks with epoxy coated reinforcing bar. As a result, the state's bridge preservation strategy focuses on using concrete with low-permeability to limit water that seeps through the concrete to the reinforcing bar. KDOT also uses common practices to design, construct, and maintain bridges to manage and prevent corrosion. For example, KDOT officials said that the state uses weathering steel to construct most of its bridges as well as, pliable material, such as rubber, for bridge joints. This helps keep water away from girder ends and abutments. KDOT has also experimented with using ultra-high performance concrete in its bridge decks and fiber-reinforced polymer for bridge deck repair. The state maintains its bridges to manage existing corrosion and prevent further corrosion by repainting existing painted bridges, increasing the overlay thickness for bridge decks, and sweeping the bridge decks on a limited basis.

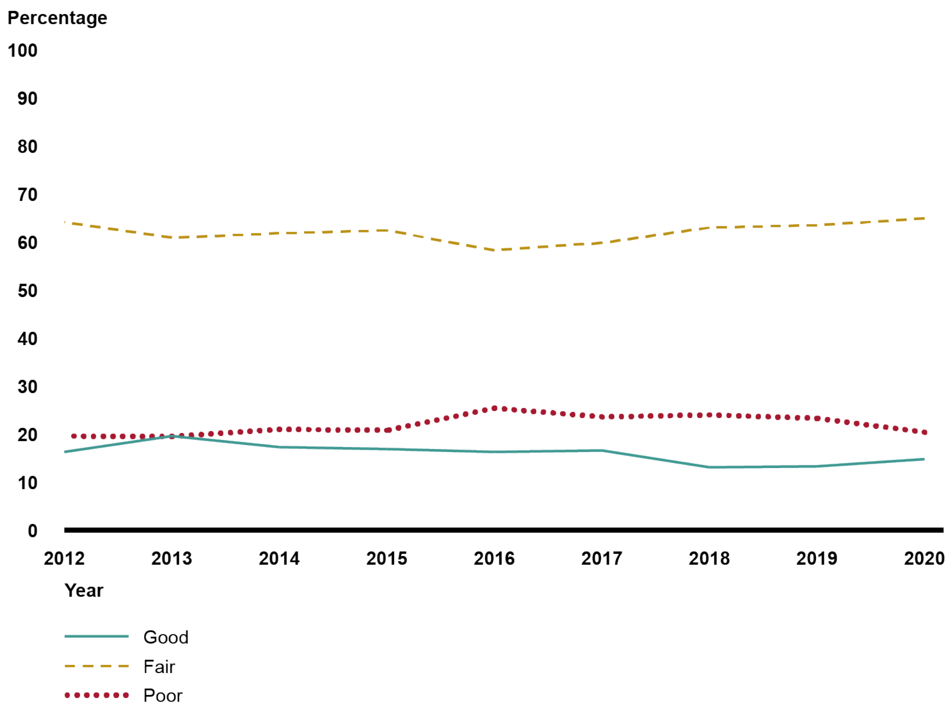
Rhode Island

Characteristics of NHS Bridges

- Number of NHS Bridges: 417[7]
- Number of concrete bridges: 161
- Number of steel bridges: 253
- Average age of NHS bridges: 50.9 years

Condition of NHS Bridges, 2012-2020

Figure 11: Percentage of the National Highway System's Bridge Deck Area Reported to be in Good, Fair, and Poor Condition in Rhode Island, 2012-2020



Source: GAO analysis of Federal Highway Administration information. | GAO-21-104249

[7]Rhode Island has three additional bridges that are not concrete or steel.

Environmental Factors Affecting Bridge Corrosion

According to officials from the Rhode Island Department of Transportation (RIDOT), the state experiences a large number of freeze-thaw cycles and uses sodium chloride as a deicer to clear roads of ice and snow. Bridges are also affected by salt water from the Atlantic Ocean. See fig. 12 for an example of corrosion on a bridge in Rhode Island.

Figure 12: Photo of Corrosion on a National Highway System Rhode Island Bridge

These two steel beams have advanced deterioration due to corrosion. The state repaired one beam and left the other for monitoring.

Source: Rhode Island Department of Transportation. | GAO-21-104249

Practices to Manage or Prevent Corrosion

RIDOT officials said that the most significant source of deterioration of steel bridges in the state is leaking bridge joints. The joints leak water, debris, salt, and other material on the steel beam below. In response, the state has made efforts to regularly replace bridge joints and has tried to limit the number of joints in new bridges. In addition, RIDOT uses common practices to design, construct, and maintain bridges to manage and prevent corrosion including high performance concrete[8] and coatings. An RIDOT official also said that it is becoming a standard practice to clean the bridges. RIDOT officials said that the state also uses cathodic protection systems on its older bridges.

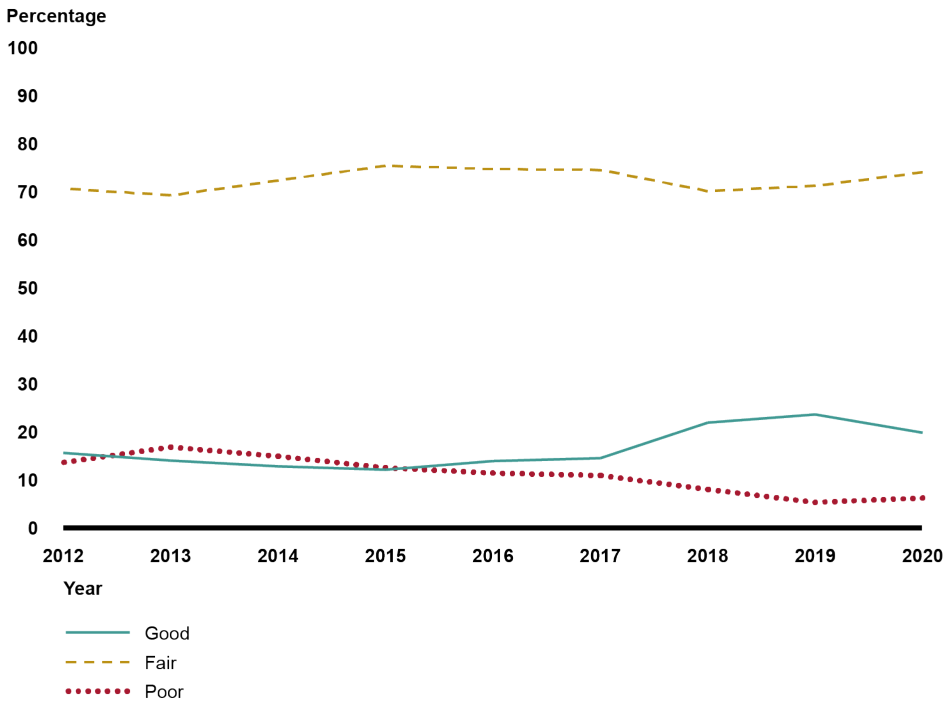
Wyoming

Characteristics of NHS Bridges

- Number of NHS Bridges: 1,343
- Number of concrete bridges: 782
- Number of steel bridges: 561
- Average Age of NHS Bridges: 48.7 years

Condition of NHS Bridges, 2012-2020

Figure 13: Percentage of the National Highway System's Bridge Deck Area Reported to be in Good, Fair, and Poor Condition in Wyoming, 2012-2020



Source: GAO analysis of Federal Highway Administration information. | GAO-21-104249

[8]High-performance concrete is concrete that has been designed to be more durable and, if necessary, stronger than conventional concrete.

Environmental Factors Affecting Bridge Corrosion

According to officials from the Wyoming Department of Transportation (WYDOT), the occurrence of corrosion is low in the state due to the arid conditions. The officials said that while the state does get a lot of snow, it has relatively low humidity, even in its more mountainous regions.

Figure 14: Photo of Corrosion on a National Highway System Wyoming Bridge

This moveable bearing has dirt and gravel debris that limits movement as wells as a loss of coating with surface corrosion on the exposed steel.

Source: Wyoming Department of Transportation. | GAO-21-104249

Practices to Manage or Prevent Corrosion

WYDOT officials said that most corrosion issues in the state are due to coating failures beneath leaking or failed deck joints, leading to coating failure and eventually, corrosion. WYDOT officials said the state uses common practices to design, construct, and maintain bridges to manage and prevent corrosion. For example, WYDOT officials said that the state has shifted its bridge design philosophy to more proactively address corrosion by, for example, using epoxy overlays on decks as bridges are constructed. The state also uses weathering steel in many of its bridges, precluding the need for painting, and eliminates bridge joints where possible. WYDOT uses deicers on its bridges to remove ice and snow when it occurs. Maintenance practices the state uses to manage or prevent corrosion include painting, including applying epoxy sealers to prevent intrusion of deicers, removing deteriorating concrete, and installing rigid deck overlays. Wyoming also installs cathodic protection systems in limited situations.

Appendix II: Comments from US Department of Transportation

U.S. Department of Transportation

Office of the Secretary of Transportation

Assistant Secretary for Adminstration

1200 New Jersey Ave., SE
Washington, DC 20590

September 13, 2021

Andrew Von Ah
Director, Physical Infrastructure
Government Accountability Office (GAO)
441 G. Street NW
Washington, DC 20548

Dear Mr. Von Ah:

Ensuring the safety of the Nation's highways and bridges is a priority for the Department of Transportation (DOT) and the Federal Highway Administration (FHWA). As GAO noted in its draft report, the percentage of National Highway System (NHS) bridges classified as in poor condition based on deck area has improved over the last decade. Further, the percentage of all bridges (NHS and Non-NHS) classified as in poor condition based on deck area has significantly reduced from 7.0 percent in 2012 to 4.2 percent in 2021. These improvements are due in part to FHWA's stewardship, oversight, and support of State departments of transportation and other stakeholders in implementing the Federal-aid Highway Program (FAHP). In addition to overseeing the FAHP, FHWA supports State DOTs and other stakeholders in the development and construction of highway projects, including providing technical assistance in the implementation of preservation activities to maintain and improve the condition of their bridges. The FHWA also conducts research to develop tools, methods, and procedures to advance the state of practice in bridge preservation.

The following are examples of bridge preservation activities FHWA has underway or completed:

- Publishing the Bridge Preservation Guide in 2018 based on peer exchanges conducted in 2017 with several State DOTs. The guide identifies commonly practiced bridge preservation activities, including techniques for addressing corrosion.
- Publishing a case study in 2020 entitled, Eliminating Bridge Joints with Link Slabs, which investigated an alternative to the replacement or repair of leaking bridge joints.
- Publishing a case study later in 2021 entitled, Utilization of Cathodic Protection to Extend the Service Life of Reinforced Concrete Bridges, which some State DOTs have successfully implemented to alleviate corrosion issues with existing bridges.
- Assigning a full-time staff member of the FHWA's Office of Infrastructure Research and Development in June 2021 to bridge preservation R&D. One of the initial assignments for this new position is the development of a bridge preservation research roadmap, which will include efforts related to corrosion issues.

Based on our review of the draft report, FHWA concurs with GAO's recommendation to ensure that its ongoing bridge preservation efforts include activities, such as peer exchanges and case studies, which focus on addressing the challenges states face with determining the circumstances under which specific corrosion practices and materials are most effective. We will provide a detailed plan to accomplish this recommendation within 180 days of final report issuance.

We appreciate the opportunity to respond the GAO draft report. Please contact Madeline Chulumovich, Director of Audit Relations and Program Improvement, at 202-366-6512 with any questions or if GAO would like additional information.

Sincerely,

Philip A. McNamara
Assistant Secretary for Administration

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

Andrew Von Ah, (202) 512-2834 or vonaha@gao.gov.

Staff Acknowledgments

In addition to the contact named above, Nancy Lueke (Assistant Director); Lynn Filla-Clark (Analyst-in-Charge); Charlotte E. Hinkle; Richard Jorgenson; Bonnie Pignatiello Leer; Ying Long; Jon Melhus; Joshua Ormond; Mary-Catherine P. Overcash; Cheryl Peterson; A. Maurice Robinson; Kelly Rubin; Pamela Snedden, and Michelle Weathers made key contributions to this report.

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